Depend on pseudo-code of FixDeC algorithm, construction of spherical cluster starts by first state the centers cluster from cloth nodes and assign the threshold density also known as radius for each cluster $\boldsymbol{r = k * SL_{max}}$. To make a group of clusters, user can set the number of clusters depend on the total of cloth nodes. The collision checking procedure only applied once a surface point contained in the cluster region $\boldsymbol{Np = \{p \in Np \,|dist(p,q) \leq r\}}$, while points not classified into any clusters are classified as noise points $\boldsymbol{Cl_n}$. noise = $\{\boldsymbol{Sp \in Np \,|\forall i: Sp \notin Cl_n}\}$. Fig. 8 illustrates an example of 2D spherical cluster construction for FixDeC technique with their surface intersection problems and Fig. 9 shows enable FixDeC spherical cluster in 3D that applied on our cloth object.

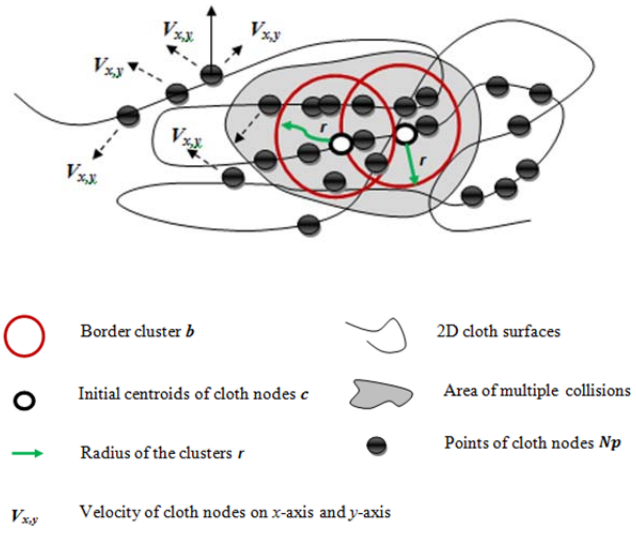

Fig. 8 FixDeC representation

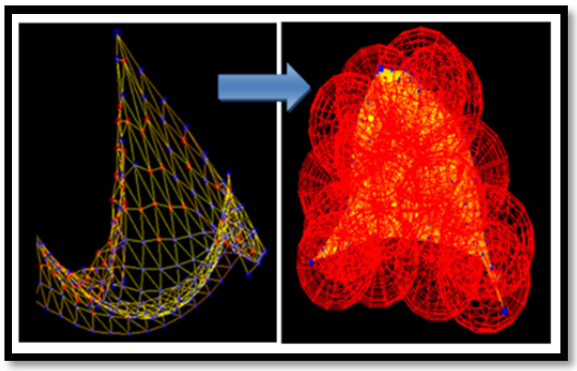

Fig. 9 FixDeC technique display

V EXPERIMENTAL RESULT

B. *Self-collision Construction Time Test of Our Improvement Method*

This testing is to test self-collision time for our improvement method (IM) compared to the particles collision method (PCM). Although our method consume much time but it can be used to solve the penetration problem compared to particles collision method. The graph of this test is illustrated in Fig. 10.

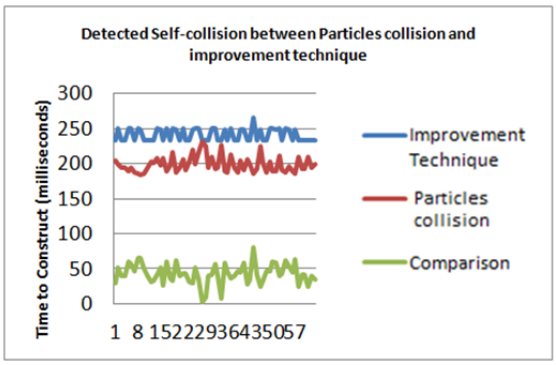

Fig. 10 Average times to construct 500 times for detected self-collision between particles collision method and our improvement particles method.

Graph in Fig. 11 showed that particles collision test is a suitable method to detect self-collision in cloth nodes simulation. By constructing 500 times for particles method, the average times is obtained. Even though our method testing is highly time consumes with an average of 260 milliseconds (52%) but our method is the best way to solve the penetration collision problem. Based on this figure, we can summaries that by using our method, 15 milliseconds (7%) achieved high construction time compared to particles collision method.

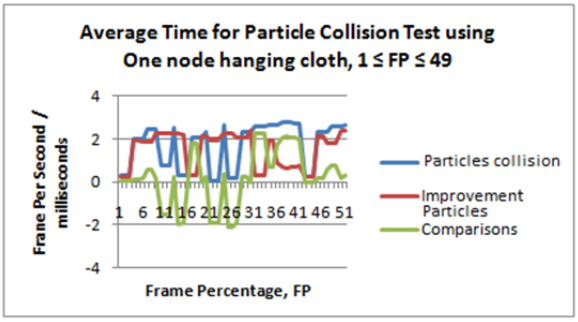

Fig. 11 Average Time for Particles Collision Test using one node hanging cloth, 1 ≤ FP ≤ 49

Fig. 11 shows the average time for particles collision test using one node hanging cloth, 1 ≤ FP ≤ 49. The testing uses PCM and our method for frame percentage collision time, FP, from 1 to 49. At FP=37 to FP=40, our method uses more time to calculate the collision testing for each frame between these approaches by 11 ms. While at FP=4, only 5 ms differences is seen between the two approaches.

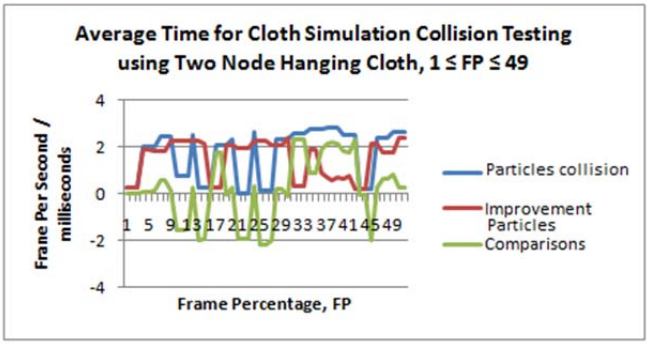

Fig. 12 Average Time for Particles Collision Test using two node hanging cloth, 1 ≤ FP ≤ 49

For average time particles collision test using two node hanging cloth, as shown in Fig. 12, the average for frame percentage using our IM is more similar with one node hanging cloth collision testing. In Fig. 13, the total average time collision testing for PCM is 16 ms while that for our method is 18 ms. From here, we noticed that our method consume more time for checking collision between particles cloth nodes compared to the PCM but the penetration problem between surface points are not penetrable even though the cloth surface is being twisted.

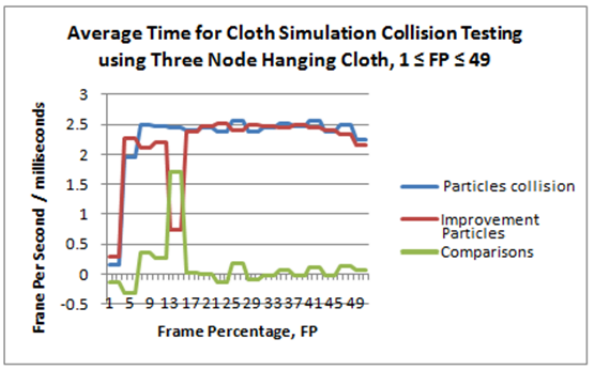

Fig. 13 Average Time for Particles Collision Test using three node hanging cloth, $1 \leq FP \leq 49$

Table 1 shows in detail about the particles collision experiment and result tests depend on graph in previous discussion.

TABLE I.
EXPERIMENT AND RESULT

	Spherical Cluster	Average Time	Summary
PCM (one hanging cloth)	No	6 ms	
IM (one hanging cloth)	No	11 ms	**
PCM (two hanging cloth)	No	9 ms	
IM (two hanging cloth)	No	13 ms	**
PCM (three hanging cloth)	No	16 ms	
IM (three hanging cloth)	No	18 ms	**

Test the performance of heuristic method
**used more time for checking but can solve the Penetration collision problem

C. Self-collision Handling Construction Time Test of FixDeC

Fig. 14 clearly showed that FixDeC is a right way of solving the self-collision problem compared to particles collision from particles collision method. By constructing 500 times for cloth FixDeC and PCM, the average times is achieved. Even though a PCM is highly accurate in most cases, the cost collisions for cloth surfaces still slow with an average of 245 milliseconds (45%) and can be reduced through the use of FixDeC technique.

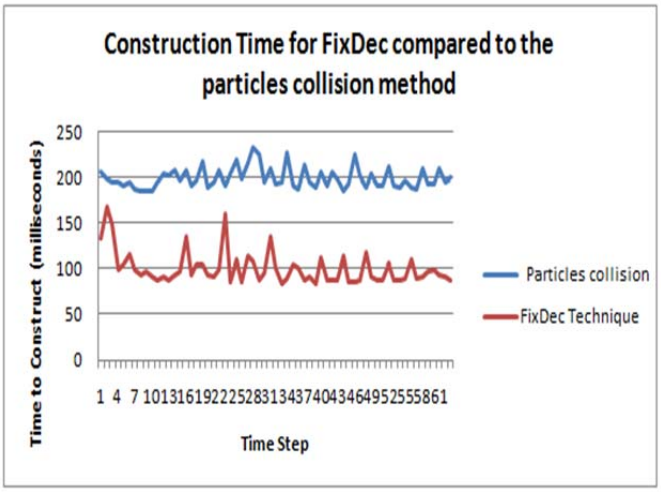

Fig. 14 Average times to construct 500 times for cloth using FixDeC and particles collision method.

From the graph in Fig. 15, the different of time construction show that the average time with FixDeC technique is better compared to without FixDeC technique. By constructing 500 times for with and without FixDeC technique in cloth, the average times is achieved. FixDeC technique produce much faster times an average of 160 milliseconds (32%) from a percentage of total frames compare to the first approach an average of 245 milliseconds (45%). Based on this figure, we can summaries that by using FixDeC technique, 85 milliseconds (13%) of calculation achieved better construction time compared to without using FixDeC technique. Table 2 shows in detail about the FixDeC experiment and result tests.

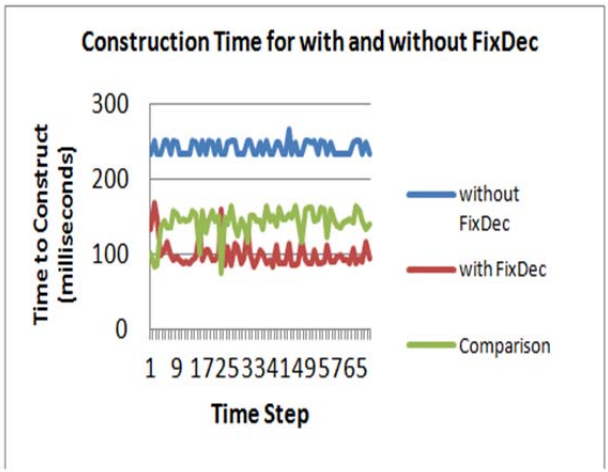

Fig. 15 Average times to construct 500 times for with and without FixDeC technique in cloth.

TABLE II.
EXPERIMENT AND RESULT

	Spherical Cluster	Average Time	Summary
FixDeC	Yes	160 ms (32%)	85 ms (13%) achieved better construction time
Particles collision method (PCM)	No	245 ms (45%)	
Improvement method (IM)	No	260 ms (52%)	15 ms (7%) achieved high construction time - can solve the penetration problem
FixDeC with PCM (one hanging cloth)	Yes	31 ms	*
FixDeC with IM (one hanging cloth)	Yes	23 ms	
FixDeC with PCM (two hanging cloth)	Yes	33 ms	*
FixDeC with IM (two hanging cloth)	Yes	30 ms	
FixDeC with PCM (three hanging cloth)	Yes	49 ms	*
FixDeC with IM (three hanging cloth)	Yes	37 ms	

The focus of this experiment lies on testing the FixDeC performance of a highly cloth model that experiences self-collision.
* used more time for checking.

IV. CONCLUSION

FixDeC technique helps in reducing the problem of handling computation self-collision detection once cloth surfaces undergone wrinkle and twist process. For the use in our cloth simulation system, we showed that clustering is the best choice which does not state the minimum number of particles that must exist in the cluster region. The collision checking procedure between cloths surfaces can only be performed once a surface point contained by the predefined spherical clusters. The implementation of FixDeC technique is successfully done in cloth simulation. This paper evaluates the performances of two techniques FixDeC with improvement particles method and FixDeC with particles collision method for difference node hanging cloth. The series of evaluation has been completed for FP in range 1 to 49. From the results, the average detection time was examined and the FixDeC with improvement particles method could produce fast and efficient self-collision handling compared to the particles collision approach. In conclusion, our technique can be used perfectly in order to handle the self-collision between cloth surfaces with better performance.

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REFERENCES

[1] Cheng, H.-H. Interactive cloth simulation, Master's thesis, Computer Science Department, University of California, Los Angeles, USA. 2009. URL: http: // www. scribd. com/ doc/ 24601463/

[2] Baraff, D., and Witkin, A.. Dynamic simulation of nonpenetrating flexible bodies. In Proc. of SIGGRAPH, ACM Press / ACM SIGGRAPH, Computer. Graphics Proc.,1992, 303–308.

[3] He, Bing, and Liu Cheng. "A Quad Tree Based Self-collision Detection Method for Cloth Simulation." Journal of Computers 5.7 2010: 1070-1077.

[4] Lv, M. Y., et al. "A fast self-collision detection method for cloth animation based on constrained particle-based model." Digital Media and its Application in Museum & Heritages, Second Workshop on. IEEE, 2007.140-145

[5] Gissler, Marc, Ruediger Schmedding, and Matthias Teschner. "Time critical collision handling for deformable modeling." Computer Animation and Virtual Worlds 20.2-3 , 2009: 355-364.

[6] Volino, P., & Thalmann, N. M., Accurate collision response on polygonal meshes. In Computer Animation 2000. Proceedings (pp. 154-163). IEEE.

[7] Provot, X. , Collision and self-collision handling in cloth model dedicated to design garments (pp. 177-189). Springer Vienna 1997.

[8] Huh, S., Metaxas, D. N., & Badler, N. I.. Collision resolutions in cloth simulation. In Computer Animation, 2001. The Fourteenth Conference on Computer Animation. Proceedings (pp. 122-127). IEEE.

[9] Fuhrmann, A., Gross, C., and Luckas, V.. Interactive animation of cloth including self collision detection. Journal of WSCG, Vol 11, 2003. No 1 pages 141- 148.