Mesh Adaptation for Object Motion with Contact

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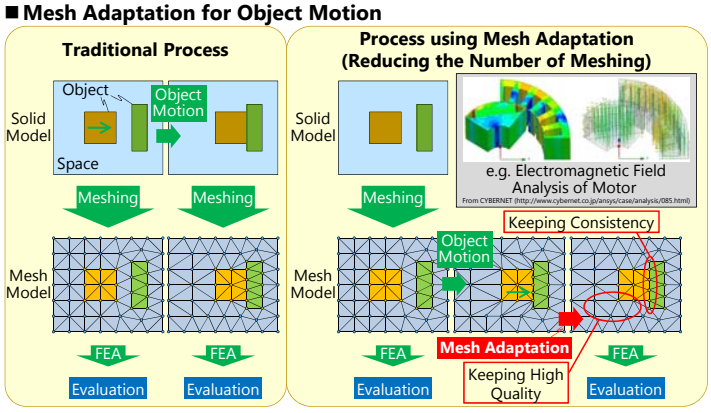
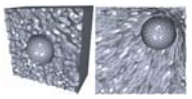
1. Background & Purpose

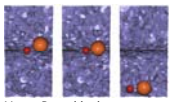
■ Mesh Adaptation for Object Motion



■ Related Works (Mesh Adaptation)

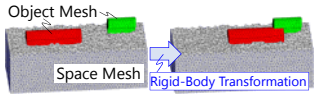
- Moving Least Square (Vertex Repositioning) [1]
- Vertex Repositioning + Local Topological Operations[2]
- × Inefficiency (Global Processing)
- × Cannot deal with the contacts of the objects


Moving Least Square[1]

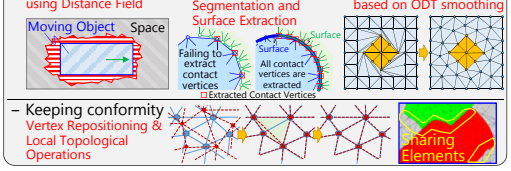

Vertex Repositioning + Local Topological Operations[2]

■ Purpose: To propose a mesh adaptation method for efficient mesh generation of each step of object motion with contact

Input
- Conformal tetrahedral mesh
  - Surface: plane, cylinder, cone, sphere, or torus
- Sequence of the rigid-body transformation matrices



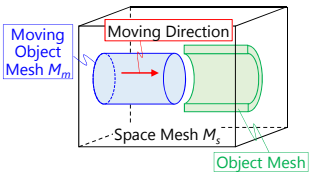
Functional Requirements & Our Method
- Efficient adaptation — Local Processing using Distance Field
- Accurate contact region extraction — Segmentation and Surface Extraction
- High quality — Quality Improvement based on ODT smoothing
- Keeping conformity — Vertex Repositioning & Local Topological Operations



2. Proposed Method

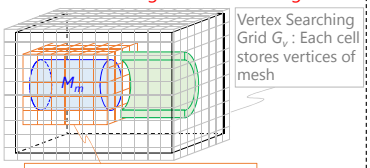
Preprocessing Step

■ Input Data



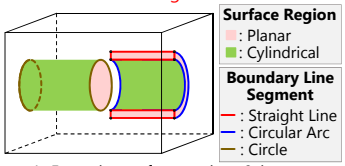
1 Grid Generation

Generating regular grids G_d & G_v for efficient extraction of deformed region & contact region



2 Segmentation[3]

Using region growing based on normal vector, principal direction, and surface fitting

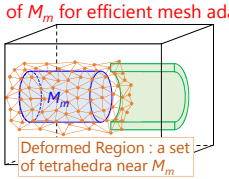


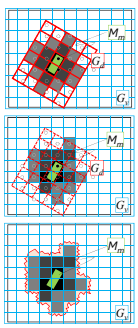
1. Extracting surfaces regions & its surface parameters
2. Extracting boundary line segments & its curve parameters

Local Region Extraction Step

3 Deformed Region Extraction

Extracting a set of tetrahedra near the surface of M_m for efficient mesh adaptation

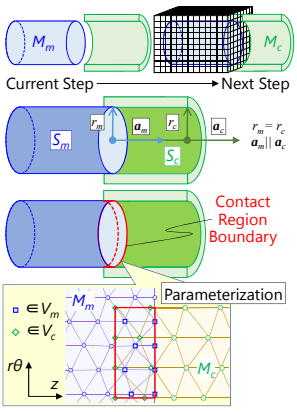




1. Assigning distance values of G_d to eachcell of G_v
2. Extracting C_v (a set of cells of G_d whose distance values are lower than a threshold)
3. Extracting a set of tetrahedra of M_s with vertices included in cells $c_{i,j,k} \in C_v$

4 Contact Region Extraction

Contact detection & extraction of the contact region using surface parameters

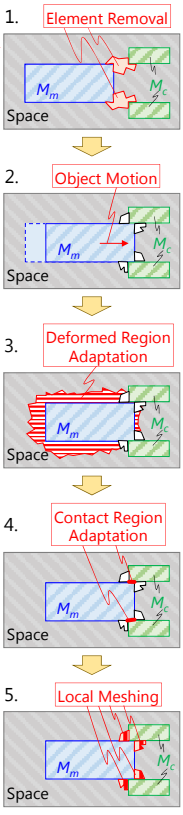


1. Extracting the contact object mesh M_c using G_d & G_v
2. Extracting contact surface regions S_m & S_c using surface parameters
3. Extracting the contact region boundary using boundary line segments of S_m & S_c
4. Extracting the contact region (V_m & V_c) by parameterization of S_m & S_c

Adaptation Step

5 Mesh Adaptation

Applying mesh deformation[3], meshing, and ODT smoothing[4]

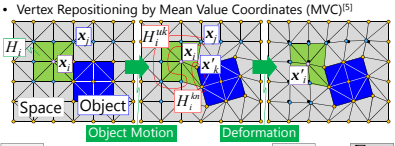


1. Element Removal (removing elements near the contact region)

2. Object Motion (rigid-body transformation)

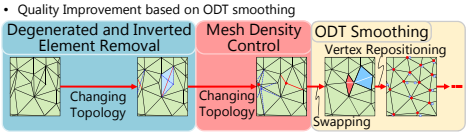
3. Deformed Region Adaptation

- Vertex Repositioning by Mean Value Coordinates (MVC)[5]



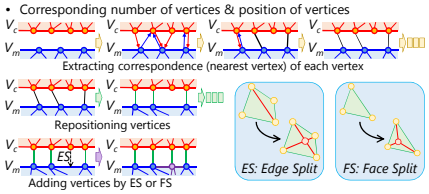
Before Object Motion: $x_i = \sum_{j \in H_i} \omega_j x_j$ (1) — H_i: A set of Handle vertices / ω_j: Weight(MVC) / I: Vertices included in deformed region ($I, ..., n$) — After Object Motion: $x'_i = \sum_{j \in H_i^{uk}} \omega_j x'_j + \sum_{k \in H_i^{kn}} \omega_k x'_k$ (2) — Position Unknown / Position Known

- Quality Improvement based on ODT smoothing

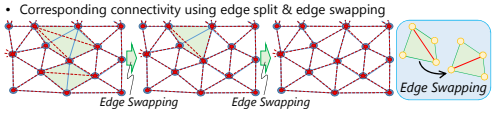


4. Contact Region Adaptation

- Corresponding number of vertices & position of vertices



- Corresponding connectivity using edge split & edge swapping



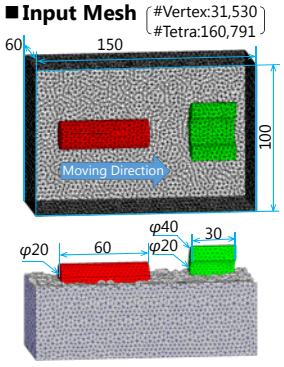
- Quality improvement by Phased ODT smoothing[3] (Improving the boundary line→the surface triangles→the inner tetrahedra)

5. Local Meshing (Constrained Delaunay Triangulation with Quality Improvement based on ODT smoothing)

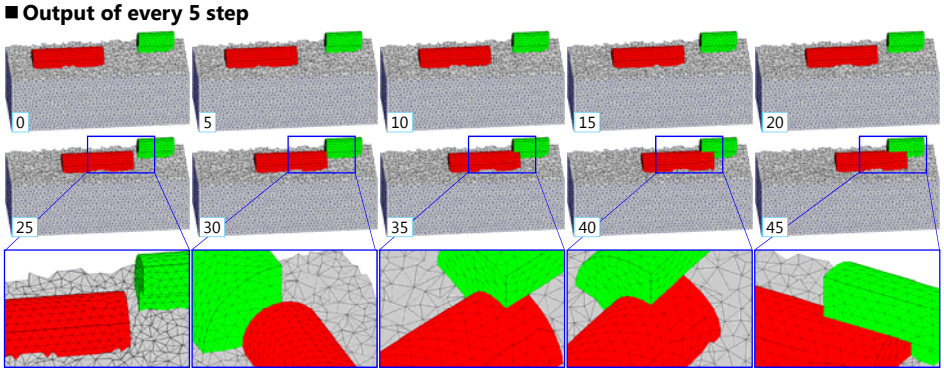
3. Results

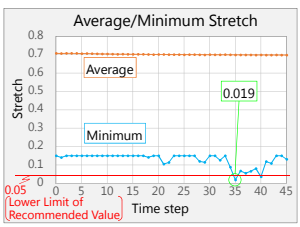
■ Input Mesh

(#Vertex:31,530 #Tetra:160,791)



■ Output of every 5 step





Stretch
1 Regular
0 Degenerated
-1 Inverted

Processing time: **294** s (6.53s / 1step)

PC
CPU : Intel Core i7 3.00GHz
RAM : 64.0GB

Enabling us to efficiently generate conformal mesh models at each time step without inverted elements

4. Conclusion

- **Development of mesh adaptation for efficient mesh generation of each step of object motion with contact**
- **Demonstration using a simple model**
- **Future Works: Improving mesh quality, application to more complex model, and check of influence to FEA**

Reference

[1] D. Sieger, S. Menzel, M. Botsch, Constrained Space Deformation for Design Optimization, Procedia Engineering, 82, 2014, pp. 114-126.
[2] C. Dobrzynski, P.Frey, Anisotropic Delaunay Mesh Adaptation for Unsteady Simulation, in: 17th International Meshing Roundtable, Sandia National Laboratories, Pittsburgh, PA, 2008, pp. 177–194.
[3] H. Maehama, H. Date, S. Kanai, Segmentation, Dimension-Driven Deformation, and Quality Improvement of Tetrahedral Mesh Models for Finite Element Analysis, in: the 15th International Conference on Precision Engineering, Kanazawa, 2015, pp. 556-561.
[4] L. Chen, Mesh smoothing schemes based on optimal Delaunay triangulations, in: 13th International Meshing Roundtable, Sandia National Laboratories, Williamsburg, VA, 2004, pp. 109–120.
[5] T. Ju, S. Schaefer, and J. Warren, Mean Value Coordinates for Closed Triangular Meshes, ACM Transactions on Graphics, 24, 3, 2005, pp. 561-566.