Research Note
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An inside-out method for arbitrary polyhedra

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Abstract

Meshes consisting of arbitrary polyhedra have gained popularity in the CFD community over the last decade, as a consequence of the advances in the solver technology. Furthermore, polyhedral meshes can be generated by retrieving the dual of a tetrahedral mesh, and there exist many methods which can generate tetrahedral meshes in complex geometries. In addition, polyhedral meshes have lower number of cells and better accuracy than their tetrahedral counterpart [4]. This note presents an effort to develop an inside-out method for generation of polyhedral meshes, which does not require high-quality input geometry, and is tolerable to small gaps, cracks and protrusions. Unlike methods which use hex-dominated templates, it is not so sensitive to the alignment of the template with the geometry because most of mesh faces have either five or six vertices. The method is tested on examples of both academic and industrial interest.

Keywords: Mesh Generation; Inside-out Meshing; Arbitrary Polyhedra; Tetrahedral Template;

1. Introduction

Many Computational Fluid Dynamics (CFD) codes are designed for unstructured meshes consisting of arbitrary types of control volumes. This has increased the interest in meshes consisting of arbitrary polyhedra, because they produce better accuracy than tetrahedral meshes, and are also comparable with boundary-aligned hexahedral meshes [4]. Polyhedral meshes can be generated automatically from tetrahedral meshes by creating a dual of the tetrahedral mesh, which can be done automatically without any user intervention. On the contrary, automatic generation of boundary-aligned hexahedral meshes is a more complex task due to the complex structure of a hexahedral mesh, which does not allow for local changes of mesh topology [10]. The compromise between the accuracy of computational results and automatic mesh generation has recently increased interest in polyhedral meshes.

The intention to use polyhedral meshes for simulation of all kinds of physical phenomena has motivated researchers to develop boundary-fitted polyhedral meshes [1,2,4,7]. The current methods for polyhedral mesh generation require clean input geometry which is not easy to achieve for complex geometries present in the industrial environment.

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On the other hand, inside-out methods [5,6,8,12,13] posses high potential for automation even for bad-quality input geometry. Wang *et. al.* [12] have presented a method which generates the mesh template from the underlying tree structure, and the stairs in the template are smoothed-out via Laplacian smoothing. The meshing process is completed by projecting the surface of the template onto the geometry, and it is not sensitive to geometrical defects which are smaller than the local cell size. Schneiders *et. al.* [8] have implemented a method which generates a wrapper layer of prismatic elements around the template, in order to improve mesh alignment and quality near the boundary. Zhang *et. al.* [13] have improved the procedure for template generation by eliminating ambiguities using dual contouring. Owen *et. al.* [6] have implemented a multi-material parallel method using MPI communication, and the internal interfaces are reconstructed from volume fractions in the input data. The method developed by Lahur *et. al.* [5] is designed to capture salient features in the mesh even they are not properly defined in the input data due to its poor quality.

This note presents the development status of an inside-out method for generation of meshes consisting of arbitrary polyhedra. It is automatic and generates volume meshes based on an input surface triangulation and the user-defined requirements stored in a settings file. The method is tolerant to poor surface quality, and does not require any user intervention during the meshing process. In order to reduce the number of faces projected onto the input geometry, a method for morphing the surface is implemented which ensures that each boundary polyhedron has only one boundary face. It is tested on examples of academic and industrial interest and it produces encouraging results. The methodology is discussed in Sect. 2. Preliminary results in presented in Sect. 3. Conclusions and suggestions for future research are given in Sect. 4.

2. Methodology

The method generates a mesh template from an octree generated using the input surface triangulation with selected feature edges and the user-defined refinement sources, see Fig. 1a. The mandatory refinement source is the maximum cell size in the domain. Other refinement sources are: boundary cell size, cell size in local regions of the input surface, refinement zones which are inside or intersect primitive objects like boxes, spheres, cylinders and lines. Furthermore, automatic octree refinement based on curvature estimation and proximity estimation is also available. The octree is refined until the leaves intersecting the surface triangulation and inside the surface are larger than the size specified by the user. The octree is also balanced such that the refinement levels of the leaves attached to a vertex do not differ by more than one. This requirement simplifies the procedure for generation of the initial tetrahedral mesh template which is then converted into a polyhedral template.

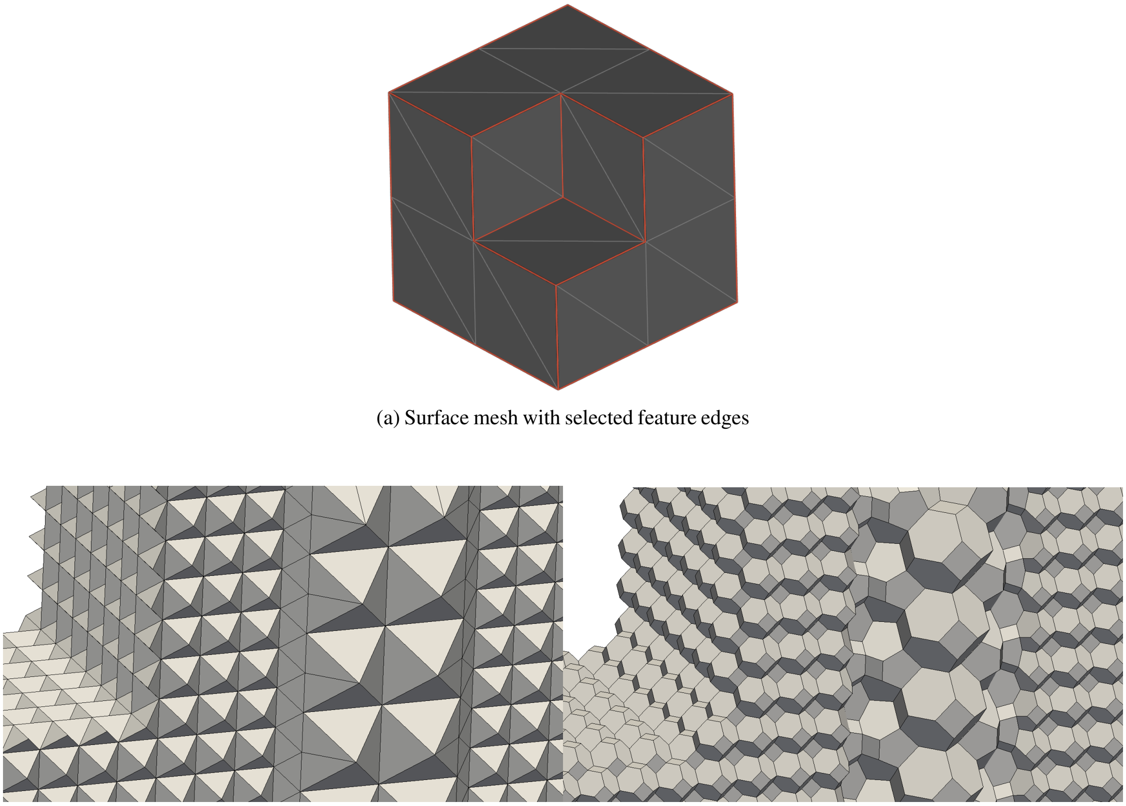
2.1. Polyhedral template generation

The process is started by generating a tetrahedral template, which is extracted from the octree based on the BCC arrangement in the spirit of Teran *et. al.* [11], by using the internal octree leaves and the adjacent layer of leaves intersected by the input surface mesh. The current approach generates the tetrahedra in the transition regions with varying octree leaf size by adding additional vertices into the octants of leaves near the vertices which share some other leaf at higher refinement level, and by using predefined templates used for generating the tetrahedra directly from the available vertices.

The polyhedral mesh template is generated as a dual of the tetrahedral mesh template. A vertex of the polyhedral mesh is generated from a cell centroids of every tetrahedron in the tetrahedral mesh. A cell is generated at every internal vertex of the tetrahedral mesh, and a face is generated at every edge by collecting the indices of vertices generated inside each tetrahedral cell comprising of the edges. The cells at the edge are sorted such that the two consecutive cells share a common face. This ensures the correct order of vertices for every polyhedral mesh face. Fig. 1c shows the polyhedral template.

2.2. Geometry preservation

The polyhedral mesh template consists of many cells with more than one boundary face. This is not desirable when projecting the mesh onto the input geometry, and the problem is tackled by implementing a procedure, named morphing, which merges boundary faces of a single cell into a single face, and ensures that every boundary face shares



(a) Surface mesh with selected feature edges

(b) Detail of the tetrahedral template (c) Polyhedral template

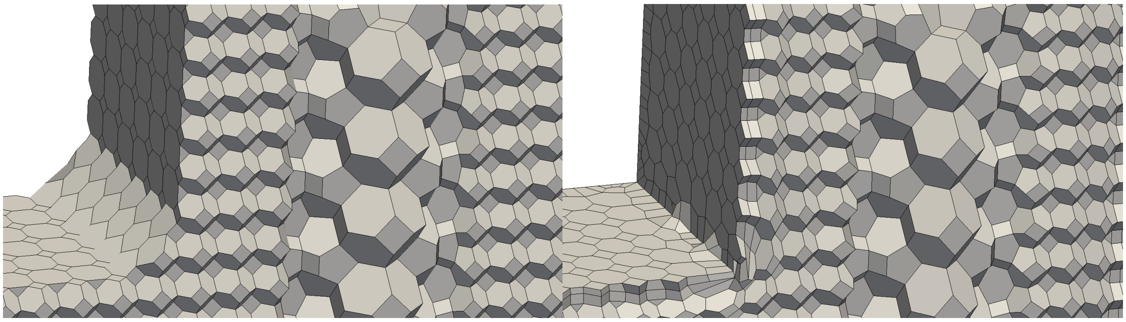
Fig. 1: Generation of polyhedral mesh template

only one edge with an internal face of the cell by merging the shared edges between the faces into a single one. The tests show that this procedure has a beneficial effect on mesh quality and reduces the meshing time as less smoothing is required, Fig. 2a.

In order to fit the template mesh onto the input geometry, the surface template is attracted to the input geometry by smoothing the remaining stairs at the surface, and by projecting the vertices onto the nearest location at the input geometry. Corner vertices and feature edges are detected using a procedure developed by Juretić *et. al.* [3], and the final topology of the mesh is obtained by adding sheets of prismatic elements as developed by Shepherd *et. al.* [9]. The procedure enables capturing of concave feature edges without the need to decompose the polyhedral cells, but it still requires smoothing and untangling to generate a valid mesh, Fig. 2b. The untangling of the mesh is performed by using the method on a tetrahedral mesh generated by decomposing the bad quality polyhedra, and each tetrahedron consists of a face centre, an edge, and a cell centre. The untangling procedure sometimes has to give up constraints in order to generate a valid mesh. This usually happens near the concave edges or corners, and this will be taken care when developing the method further.

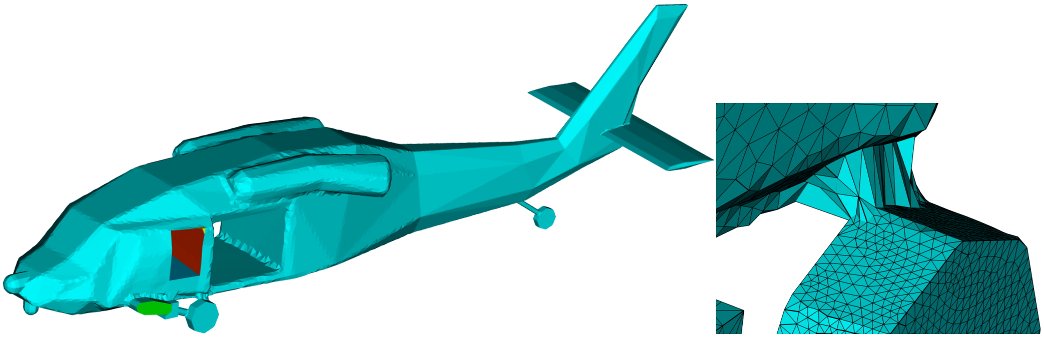
3. Preliminary results

The method was tested on a bad quality input geometry of a helicopter, Fig. 3a. The input surface has many self-intersections, and there are many regions which are not smooth, Fig. 3b. The volume generated on the external side has half a million cells and it is generated in 2 minutes on a computer four processors with eight cores in total running at 2.4GHz. The quality measured in terms of non-orthogonality and skewness, defined in [4] is given in Table 1. The resulting volume mesh is shown in Fig. 4a and Fig. 4b. The average quality of the mesh is quite high with



(a) Morphed template (b) Final mesh

Fig. 2: Polyhedral meshing process



(a) Surface mesh (b) Detail near the wheel

Fig. 3: Input geometry for the helicopter example

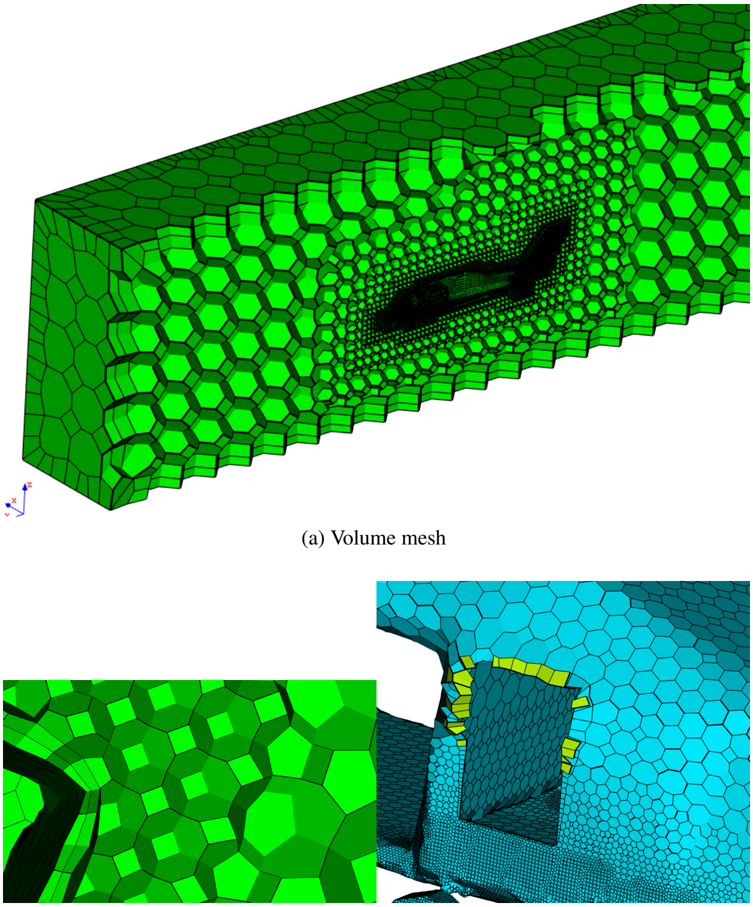
Table 1: Mesh quality for the helicopter example

Quality measure	Non-orthogonality (*deg*)	Skewness
Maximum	82	6.7
Average	7.3	0.092

a few bad quality faces near the body, Fig. 4c, where the mesh resolution is quite coarse, and the mesher struggles to capture the concave edges present there. It is believed that this behaviour can be improved by improving the procedure for capturing of feature edges, and in addition, by improving the smoothing procedure.

4. Conclusions and Future Work

The note presents the current status of a method for inside-out generation of meshes consisting of arbitrary polyhedra. The initial mesh template is created by building a tetrahedral mesh from the underlying octree, followed by the creation of the dual of the tetrahedral mesh. In order to reduce the number of boundary faces, a novel morphing algorithm is implemented. The method is capable of capturing most of salient features, and still requires some improvement in case of corners where both concave and convex feature edges meet. In addition, the method can be further enhanced by implementing more advanced smoothers which do not require decomposition of polyhedral cells into tetrahedra, and by implementing a procedure for increasing node valence needed to capture corners with valence greater than three.



(a) Volume mesh

(b) Detail near the boundary

(c) Bad-quality faces

Fig. 4: Volume mesh for the helicopter example

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