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Software update

Update (2.0) to *MiniSurf* —A minimal surface generator for finite element modeling and additive manufacturing

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ABSTRACT

This is an update to PII: S2665963820300178.

We present an updated version *v2.0* of our minimal surface generator *MiniSurf v1.0*, that creates triply periodic minimal surface (TPMS) computer-aided design (CAD) files for both finite element modeling and additive manufacturing. Besides making the GUI more user-friendly, in this new version we significantly improve the mesh quality of the generated CAD files by incorporating a mesh smoothing feature. With this new smoothing feature, *MiniSurf v2.0* can now produce high quality CAD files for more accurate finite element modeling and more precise additive manufacturing.

Code metadata

Current Code version	*v2.0*
Permanent link to code/repository used for this code version	https://github.com/SoftwareImpacts/SIMPAC-2020-40
Permanent link to Reproducible Capsule	https://codeocean.com/capsule/1851964/tree/v2
Legal Software License	*MIT*
Code versioning system used	*None*
Software code languages, tools, and services used	*Matlab*
Compilation requirements, operat-ing environments, & dependencies	
If available Link to developer docu-mentation/manual	
Support email for questions	mengtinh@uci.edu *and* Valdevit@uci.edu

Software metadata

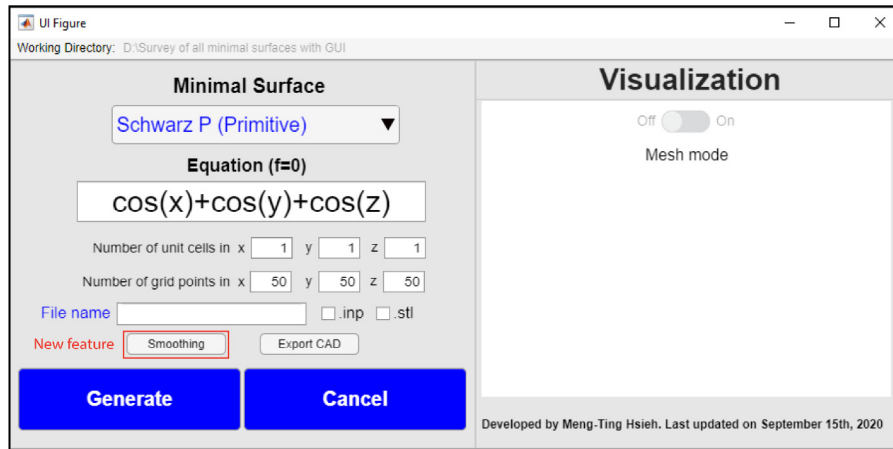|	
Current software version	*v2.0*
Permanent link to executables of this version	https://github.com/mengtinh/MiniSurf_v2.0
Permanent link to Reproducible Capsule	https://codeocean.com/capsule/1851964/tree/v2
Legal Software License	*MIT*
Computing platform / Operating System	*Microsoft Windows*
Installation requirements & dependencies	*Matlab Runtime*
If available Link to user manual - if formally published include a reference to the publication in the reference list	https://github.com/mengtinh/MiniSurf_v2.0/blob/master/User%20Manual.pdf
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Fig. 1. Display of MiniSurf v2.0 GUI with the smoothing feature highlighted in red.

1. Introduction

One of the major limitations we discussed in *MiniSurf v1.0* is the generation of CAD files with suboptimal meshes (long and narrow triangular facets resulting from the meshing of very complex topologies based on the 3D uniform grid points) [1]. The low-quality mesh often results in the inaccurate prediction of the local stress field (undesirable especially when the peak stress in an implant is estimated [2] or when a local failure criterion is used such as in the case of the fracture toughness modeling of cellular materials [3]) in a finite element simulation and the poor manufacturing of 3D printed parts (missing faces and geometric imprecision). To address this issue, we added the mesh smoothing feature that was previously used to obtain the smooth spinodal shell-based structures [4–7].

2. Smoothing algorithm and feature

The mesh smoothing algorithm is based on the Laplacian smoothing detailed in [8] and briefly described below:

$$x'_j = \frac{1}{N} \sum_{i=1}^{N} x_i \qquad (2.1)$$

$$y'_j = \frac{1}{N} \sum_{i=1}^{N} y_i \qquad (2.2)$$

$$z'_j = \frac{1}{N} \sum_{i=1}^{N} z_i \qquad (2.3)$$

where N is the total number of the neighboring nodes i, each of which connects to a mesh node j by a single mesh edge; x'_j, y'_j, and z'_j are the new x, y, and z coordinates of the mesh node j found by taking the average of x_i, y_i, and z_i, the current x, y, and z coordinates of nodes i respectively.

To preserve the periodicity of the generated TPMS mesh, the Laplacian smoothing is only applied to the interior mesh nodes, so the boundary nodes remain unchanged. The smoothing algorithm is incorporated in the smoothing push-button in the left control panel of the GUI as shown in Fig. 1. Note that every time the button is pushed, it is equivalent to applying equation (2.1), (2.2) and (2.3) six times (this has been found in general to produce an optimal balance between the smoothness and shrinkage of a given mesh) as shown in Fig. 2. The mesh smoothing can be executed iteratively to the generated triply periodic minimal surface (TPMS) mesh at user's discretion. The smoothing algorithm is also parallelized (currently set to six processors or less depending on its availability) for the efficient computation of the smoothed mesh. Furthermore, we decouple the visualization and the CAD file generation in the GUI with the addition of the "Export CAD" button as shown in Fig. 1 providing a more convenient, intuitive, and user-friendly experience.

3. New advantages and impact overview

We previously showed that *MiniSurf v1.0* can efficiently create CAD (a mesh made of many triangular facets) files of 19 common TMPSs for finite element modeling and additive manufacturing. These TPMSs have been studied extensively in multidisciplinary fields [9–17] due to their large surface area with very uniform double curvatures (directly related to the quality of underlying mesh [18–20]); hence it is extremely essential to ensure that the generated CAD files have high quality meshes consisting of triangular facets with aspect ratio close to one (not realizable in *MiniSurf v1.0*).

MiniSurf v2.0 is built to address this challenge by incorporating the Laplacian smoothing [18,21] feature detailed in Section 2. We emphasize the advantages of *MiniSurf v2.0* over *v1.0* as follows: (1) Users can control the smoothness of the generated mesh and hence the underlying mesh curvatures. (2) The mesh smoothing is highly parallelized (up to six processors by default). A finely meshed surface (300 × 300 × 300 triangular facets) can be smoothed under three seconds. (3) Most importantly, the generated TPMS CAD files now have high quality mesh for more accurate finite element modeling and more precise additive manufacturing. *MiniSurf v2.0* is currently being used in the following ongoing projects: (a) Whipple shield design — SPH modeling of hypervelocity impact on sandwiched TPMSs. We replace the traditional whipple shield design (a front bumper and a back plate) with the sandwiched primitive TPMS (smoothed and generated by *MiniSurf v2.0*). We then model the hypervelocity impact of a space debris (represented by a sphere projectile traveling at the speed of 6 km/s) using smoothed particle hydrodynamics (following similar procedures in [22]). (b) Fracture toughness of 3D cellular materials — minimal surface-based versus strut-based topologies. We investigate the mode-I fracture toughness of primitive TPMS (smoothed and created by *MiniSurf v2.0*), octet, and cubic lattices by performing finite element calculations of the J-integral on a single-edge-notch-bend (SENB) specimen (the numerical approach is detailed in [3]).

We expect *MiniSurf v2.0* to be impactful in multidisciplinary fields just as the *MiniSurf v1.0* given the recent growing interest in building new multifunctional materials with TPMS topologies. Furthermore, with high quality CAD files (smoothed and generated by *MiniSurf v2.0*) researchers can now make more accurate finite element predictions and more precise prototyping to better design the materials.

4. Conclusion

In this work, we added the mesh smoothing functionality based on the Laplacian smoothing to our previously developed software *MiniSurf*. TPMS CAD files can now be efficiently created with a user-controlled smooth mesh for more accurate finite element modeling and sound
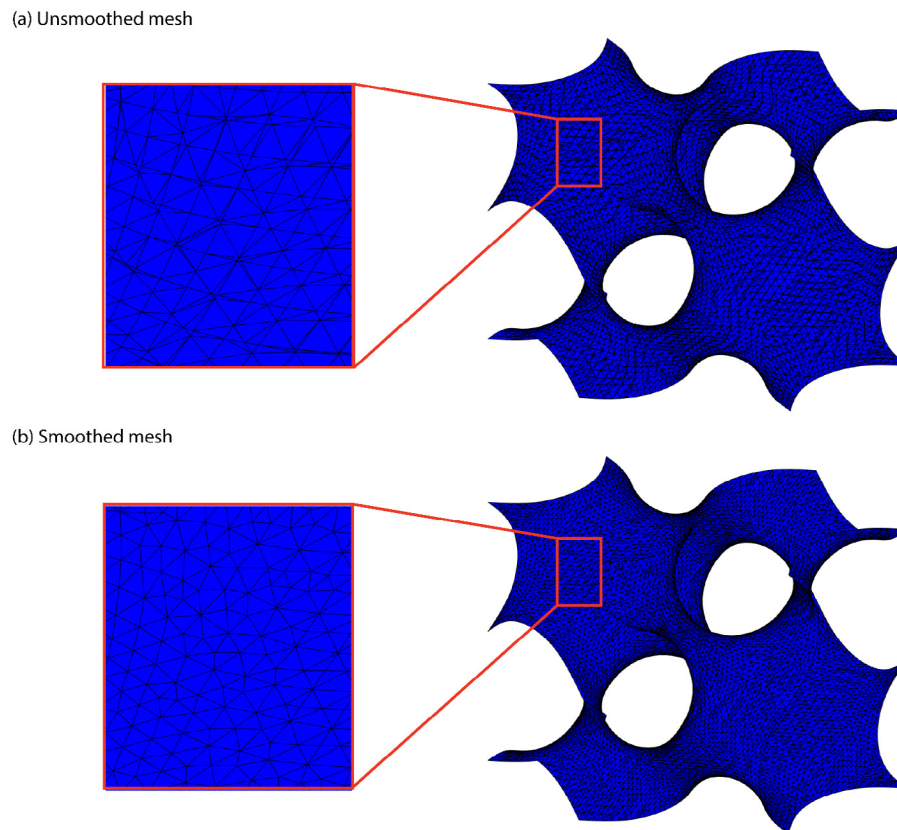
(a) Unsmoothed mesh

(b) Smoothed mesh

Fig. 2. Illustration of (a) unsmoothed gyroid mesh and (b) smoothed gyroid mesh with the zoom-in region shown in the red rectangular box.

additive manufacturing. In the future, we will continue to tackle the remaining limitations mentioned in *MiniSurf v1.0* [1]. Furthermore, we will regularly add new TPMS to our existing library.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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