Title:
Retaining Circular Features on Deforming Subdivision Surface

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Introduction:
In engineering design, designers are always facing the problem of modify existing design to fulfill new application requirements. In this process, existing object shapes may have to be deformed while special shape features are retained by including constraints in the model based on the application requirements. Retaining features while modifying regular objects to freeform objects is always a challenging problem for existing engineering CAD software. Most of the CAD software use CSG-tree and NURBS surface representation, which is effective in modeling regular engineering objects and is accurate in describing the dimension of features. However, CSG-tree is inefficient in representing freeform objects. NURBS surfaces are essentially four-sided, which limits user to model shapes with general topology.

Subdivision surface is a better candidate than NURBS when it comes to representing freeform objects. It is capable of generating smooth surface with irregular topology, allowing user to model freeform object efficiently. Multi-resolution editing is also supported when using subdivision surface. Editing can be performed on coarse initial mesh and propagate to fine mesh, saving time and complexity for mesh editing. With the above advantages, subdivision surface is widely used in the animation industry. However, in engineering design, subdivision surface is usually not adopted as modeling primitives. This is mainly due to two reasons: 1. Subdivision surface cannot be expressed explicitly and 2. The instability caused by extraordinary vertices. This makes subdivision surfaces difficult for modeling high precision features, limiting them to be used in conceptual design in existing CAD systems.

In this paper, we combine mesh deformation technique and subdivision surface for the purpose of retaining features while editing the general shape of the object. A local/global optimization scheme is used to solve the constrained deformation problem in order to retain the user-selected engineering feature in a deformation. On the other hand, smoothness of model and multi-resolution editing are achieved by using subdivision surface, which facilitates user to model freeform object. We also need to compensate the possible shrinkage due to the application of the approximating subdivision scheme to the model. Both the shape and dimension of the engineering features need to be maintained after deformation. The initial mesh is scaled up to compensate the shrinkage. Given the mesh of a regular object, our method can facilitate user in redesigning of general shape of the object to make it more attractive. At the same time, circular engineering features can be maintained, saving time and effort to rebuild the engineering features or redesign component to fit in the deformed shape.

Main Idea:
We apply Loop subdivision surface [2] to refine user input mesh. It is an approximating subdivision scheme applied on triangular mesh. User can edit the initial mesh to get a desired freeform shape by directly editing the position of the vertices. A smooth mesh can be formed by subdividing the initial mesh. The extraordinary vertices of Loop subdivision surface are C1-continuous, while the regular

vertices are C2-continous [3]. Moreover, multi-resolution editing can be achieved by subdivision surface, facilitating user to edit the model.

There are three stages in our proposed method of model editing. They are Shape editing, Features retention and Initial mesh adjustment. Our method requires user to provide a 3D mesh model as input. The target outcome is the limit surface of a subdivision surface which is a smooth surface with the desired freeform shape and retained engineering features. Fig. 1 and Fig.2 show the result of our experiment. Tab.1 and Tab2 summarize the experiment result.

In the first stage, user need to provide a 3D triangular mesh model and specify the engineering features to be retained under deformation. The vertex position of these features is stored. The input mesh is taken as the initial mesh of the subdivision surface. All the vertices of the input mesh are the control vertices of the subdivision surface. User edits the model by moving the control vertices. The deformation is propagated to the limit mesh. This will give a deformed initial mesh with desired shape as shown in Fig. 1b.

In the second stage, we need to retain the circular engineering features deformed during the editing process. We use an alternating local/global optimization method – Shape-Up [1] to retain the feature. Bouaziz and colleagues [1] developed the Shape-Up method to model 3D objects with shape constraint. A projection operator is applied to the current point set involved in the constraint. A shape proximity function is formulated as the squared distance between the current point set to the projected point set. The optimal vertices position are located by minimizing the shape proximity function. For the details of Shape-Up method, please refer to [1]. Detail preservation can be achieved by only allowing the desired feature to perform isometric transformation while the non-preserving elements can be deformed freely. The projection operator for detail preservation is the isometric transformation matrix of the vertices from initial mesh to deformed mesh. The transformation parameters are obtained by least square estimation proposed by [4]. We multiply the feature vertices on input mesh with the isometric transformation matrix. These vertices are the constraints in the optimization procedure. The retaining features procedure is performed on the initial mesh, shown in Fig.1c. We obtain a smooth mesh with desired shape and retained engineering features after subdividing the feature retained mesh.

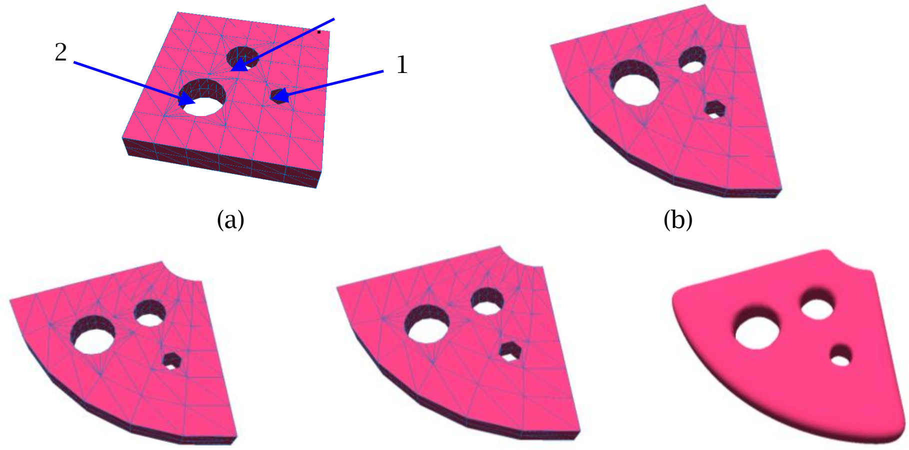
The final stage is to compensate the shrinkage of the model due to the Loop subdivision process. The shrinkages of each feature are different. It depends on the initial mesh quality, the number and the position of extraordinary vertex. Radius of the circular features is compared before and after the subdivision to determine the scaling factor of each feature. The scaling factors are applied to the corresponding features vertices and the initial mesh. Each scaled feature and scaled mesh is treated as the constraint in the local/global optimization problem to obtain the initial engineering feature size on the smooth limit mesh as shown in Fig. 1e.

	Radius on adjusted Initial mesh	Radius on adjusted Limit mesh	Target radius
Feature 1	0.415995	0.348929	0.35
Feature 2	0.820181	0.801573	0.8
Feature 3	0.628302	0.600672	0.60

Tab. 1: Result of adjusted mesh shown in Fig. 1

	Radius on adjusted Initial mesh	Radius on adjusted Limit mesh	Target radius
Feature 1	1.0358	1.00641	1
Feature 2	0.553111	0.49999	0.5

Tab. 2: Result of adjusted mesh shown in Fig. 2.



(a) (b)

(c) (d) (e)

Fig. 1: (a) User input mesh, (b) Deformation without constrains, (c) Deformation with constrains: Retained feature shape from deformation, (d) Scaled up of (c) to compensate shrinkage by Loop subdivision surface, (e) Limit surface with retained shape and size of the features.

Conclusion:

We presented a framework to retain circular feature shape and size on deforming subdivision surface. Local/global optimization framework is used to retain circular feature shape on initial mesh. After that, scaling factor of each feature is evaluated base on the difference in radius of the circular features between the initial mesh and the limit mesh of a subdivision surface. The scaling factors are applied to corresponding features and the initial mesh. The scaled features and meshes are obtained by using the local/ global optimization framework to determine an optimum initial mesh that compensates the shrinkage due to Loop subdivision surface. Experimental results showed that circular features shape and size can be retained on Loop subdivision surface. In summary, constrained deformation can be combined with subdivision surface to retain circular feature shape and size in a multi-resolution manner.

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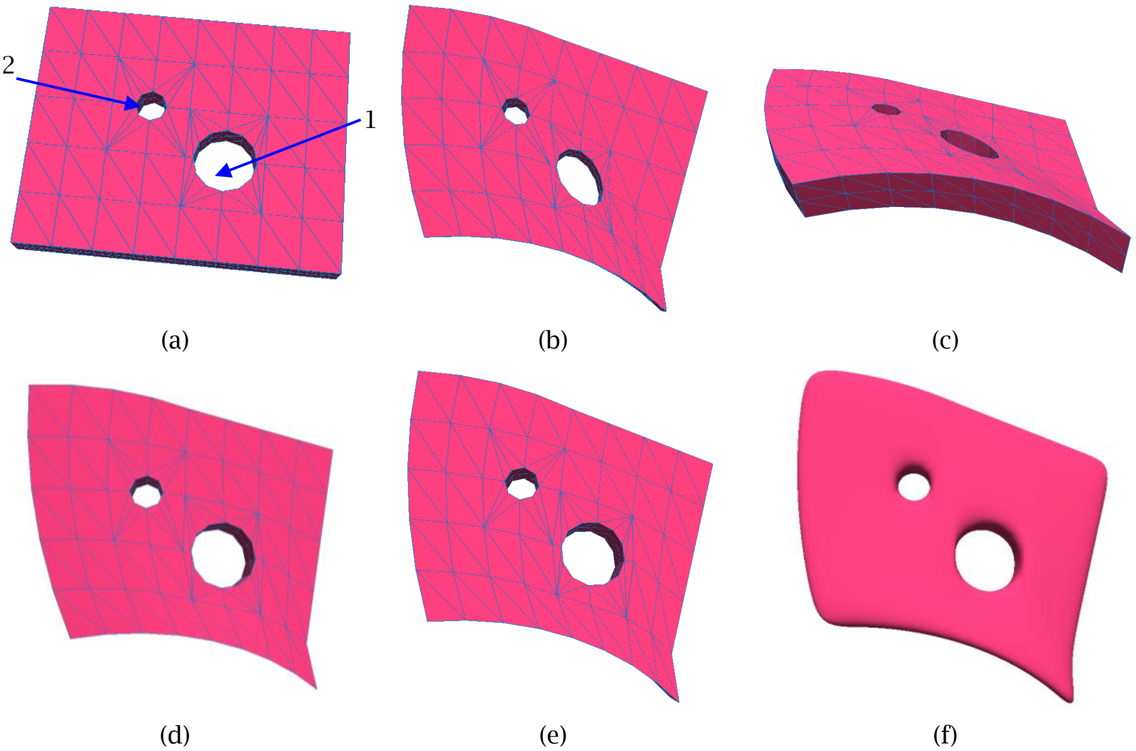

Fig. 2: (a) User input mesh with feature 1 and feature 2 denoted, (b) Deformation without constrains, (c) Another view of deformed model, (d) Deformation with constrains: Retained feature shape from deformation, (e) Scaled up of (b) to compensate shrinkage by Loop subdivision surface, (f) Limit surface with retained shape and size of the features