Developable Surface Segmentation For CAD Models

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ABSTRACT

We present a novel method to segment CAD models into developable patches by detecting curve-like features on Gauss images of the corresponding patches. A region-growing approach is employed to detect planar and curved developable patches. The Gauss image of each segmented patch is constrained to be curve-like via principal component analysis and Pearson correlation analysis. Experimental results demonstrate that our approach generates nice results on CAD models with all kinds of developable surfaces.

KEYWORDS

Developable surface, Segmentation, CAD models

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1 INTRODUCTION

Developable surfaces are widely used in industrial manufacturing and architectural modeling. Current methods for developable surfaces design generally require a clean segmentation setup which segments a mesh into developable strips and planes [Solomon et al. 2012; Tang et al. 2016], such as a segmentation in Fig. 1.

Existing approaches for developable segmentation cannot guarantee a nice result on CAD models. Julius et al. [2005] segment the mesh by detecting a subclass of developable surfaces. [Yamauchi et al. 2005] generate disk-like patches, but non-disk patches such as cylinders appear in CAD models quite often. Sharp creases in CAD models can also be a problem in recent research[Ion et al. 2020].

In this poster, we propose a novel method for extracting developable patches from CAD models by detecting curve-like features on Gauss images of each patch. The advantege of having curve-like Gauss image on each patch is that the patch can be fitted by a developable strip, which can be used in downstream applications directly. An example of our approach is shown in Fig. 1.

2 PRELIMINARIES

Smooth developable surfaces. Differential geometry offers profound insights into the nature of smooth developable surfaces.

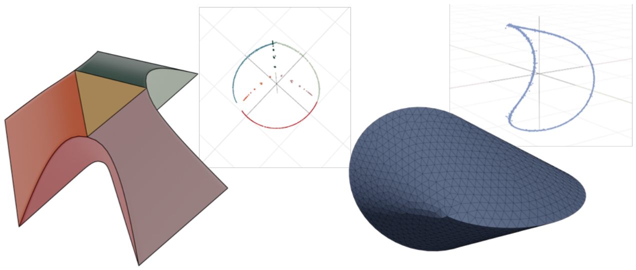

Figure 1: Left: Our result on bridge model and its Gauss image. The model is segmented into seven developable patches which include a yellow plane triangle at top and six developable strips. Right: Our result on oloid model and its Gauss image. The model has one developable surface.

Smooth developable surfaces are locally isometric to planes, such isometry can be characterized by vanishing Gaussian curvature at all points. This definition is advantageous to recognizing a developable surface rather than generating one. An efficient way to generate developable surfaces is to draw them as torsal ruled surfaces. A torsal ruled surface S can be parameterized by $S(u,v) = \lambda(u) + v\gamma(u)$, $(\lambda'(u) \times \gamma(u)) \cdot \gamma'(u) = 0$, where $\lambda(u)$ is a curve in $\mathbb{R}^3$ called directrix, $\gamma(u)$ is a nonvanishing vector field along $\lambda(u)$ specifying the direction of rulings, and the equation on the right constrains Gaussian curvature to be zero. Furthermore, the normals of the torsal ruled surface is given by $n(u) = \frac{\lambda'(u)\times\gamma(u)}{\|\lambda'(u)\times\gamma(u)\|}$. Since $n(u)$ is single parameterized, it forms a single curve in the sphere.

Gauss map of triangle meshes. Given a triangle mesh $M = \{V, F\}$ with vertice set V and face set F, the Gaussian map G of M maps each face f_i to face normal n_i. The Gauss image for M is $N = \{n_i | i = 1 \ldots m\}$. Our goal is to find curve-like point clouds from N.

Linearity. To find curve-like point clouds, we measure the linearity locally. In statistics, the Pearson correlation coefficient measures the linear correlation between two sets of data. [Lee 2000] use this coefficient to measure the linearity of a point set in $\mathbb{R}^3$. For a point set N, map it to 2d plane such that the principle direction of the result point set P coincides with the identity line, then the Pearson correlation coefficient of P measures the linearity $L(N)$ of N. If N forms a line, $L(N)$ would be close to 1. If N is distributed randomly, $L(N)$ would be close to 0.

3 METHODOLOGY

Our algorithm processes regular triangle or quadrilateral meshs. The workflow is shown in Fig. 2. We use a region-growing method to detect planes and developable patches. A seed face used for growing is chosen from regions as flat as possible. During growing

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iteration, we constrain the neighbor of each face in the patch has a curve-like Gauss image. We say a face $f_j \in F$ belongs to the i-neighbor U_k^i of $f_k \in F$ if there exists at most $i + 1$ faces $\overline{f}_1 = f_k, \overline{f}_2, \ldots, \overline{f}_{i+1} = f_j$ in F such that $\overline{f}_l$ and $\overline{f}_{l+1}$ $(l = 1 \ldots i)$ have commn edges. The principle value and principle direction of a face set I_k is the maximum principle value and the coresponding principle vector of $\{n_j - \bar{n}_k | n_j \in G(I_k)\}$, $\bar{n}_k$ is the mass center of $G(I_k)$. The principle direction and the principle value of a face f_k is the principle direction and the principle value of U_k^2.

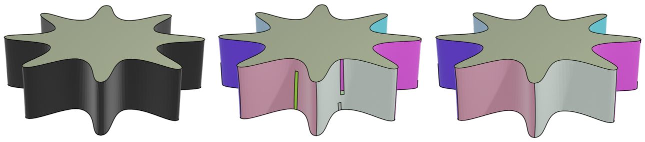

Figure 2: Workflow of our algorithm. Left: plane detection with $a_p = 0.001$; Middle: developable surface segmentation with $L = 0.94, C = 0.9$ generates 19 patches; Right: segmentation clean generates 10 patches.

Plane Detection. Our method first detects planar rigions M_p of M. Faces with priciple values less than a_p can be used as seeds. We grow a seed f_k by iteratively adding neighbor faces into segments I_k and constraining the principle value of $G(I_k)$ to be less than a_p.

Developable Surface Sgmentation. This stage detects non-planar developable pieces of $M \setminus M_p$. The seed face set $S_k = \{f_k, f_1, f_2\}$ in this step is given by the face f_k with minimum principle value and f_1, f_2 are chosen from U_k^1 such that the principle direction of S_k is closest to the principle direction of f_k. During the growing process, we constrain the linearity $l_j = L(G(U_{f_j}^2 \cap S_k))$ and tangent direction consistency c_j to be less than L and C respectively for each candidate face f_j. To guarantee $G(S_k)$ can be approximated by a curve without branch road, we compute the tangent direction consistency $c_j = \max_{t_l \in T_j} |t_l \cdot t_j|$, where T_j is the set of principle directions for faces in $U_l^2 \cap S_k$ and t_j is the principle direction of f_j.

Segmentation Clean. Our algorithm may produce small patches due to noise on the mesh or improper custom parameter choice (see figure2 middle). We clean these small patches by deleting patches with face number small than s and grow remaining patches with relaxed prarameters a_p, L and C. Both L and C disallow rapid changes on the normal of a small region. In order to group the equator side of the gears model together, L and C need to be reduced to 0.6.

4 EXPERIMENTAL RESULTS

To find appropriate L and C, we segment gears model using different parameters. See table 1 for the number of segment patches. When C is larger than 0.99, L hardly effects the result. When C is reduced to 0.8, our algorithm starts to group side faces into one patch and generate small patches along the gear corner. When C is between 0.94 and 0.9, the behavior of our algoritm is more predictable since patch number will reduce as L reduce. When L is between 0.8 to 0.94, the results are cleaner. Thus L and C can be chosen between $[0.8, 0.94]$ and $[0.94, 0.9]$ respectively. All results generated within this range will be cleaned into 10 patches after segmentation clean.

Table 1: patch number of developable surface segmentation for gears model using different parameters

	C=0.99	C=0.94	C=0.9	C=0.8
L=0.99	103	64	59	60
L=0.94	101	64	19	12
L=0.9	101	33	18	20
L=0.8	101	33	17	18

Our method generates promising results for CAD models (see Fig. 3). In these examples, a_p is set to 0.001 for plane detection. Both L and C is set to 0.9 for developable surface detection. During the clean process, a_p is relaxed to 0.02, L and C is relaxed to 0.7. Notice that a developable patch will not expand into non-developable patch. The shape of the green patch in the first modle in Fig. 3 is like part of a bending tube, which is non-developable, and it will not be merged with neighboring developable patches. Our algorithm also works on developable surfaces that are not uni-axial conics such as oloids in Fig. 1 on the right.

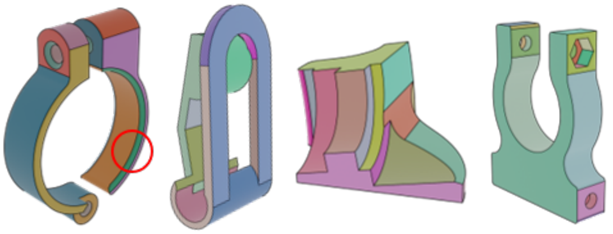

Figure 3: More results of our proposed method.

5 CONCLUSION AND FUTURE WORK

We propose an efficient method to segment CAD models into developable surfaces. Our results can be used as a setup to fit a model with developable surfaces. For noisy meshes, our method may not generate smooth boundaries. In future work, we will fit these segments with smooth developable surfaces and deal with the boundary.

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REFERENCES

Alexandra Ion, Michael Rabinovich, Philipp Herholz, and Olga Sorkine-Hornung. 2020. Shape Approximation by Developable Wrapping. *ACM Trans. Graph.* 39, 6, Article 200 (Nov. 2020), 12 pages.

Dan Julius, Vladislav Kraevoy, and Alla Sheffer. 2005. D-Charts: Quasi-Developable Mesh Segmentation. *Computer Graphics Forum* 24, 3 (2005), 581–590.

In-Kwon Lee. 2000. Curve reconstruction from unorganized points. *Comp. Aided Geom. Design* 17, 2 (2000), 161–177.

Justin Solomon, Etienne Vouga, Max Wardetzky, and Eitan Grinspun. 2012. Flexible Developable Surfaces. *Computer Graphics Forum* 31, 5 (2012), 1567–1576.

Chengcheng Tang, Pengbo Bo, Johannes Wallner, and Helmut Pottmann. 2016. Interactive Design of Developable Surfaces. *ACM Transactions on Graphics* 35, 2, Article 12 (Jan. 2016), 12 pages. https://doi.org/10.1145/2832906

Hitoshi Yamauchi, Stefan Gumhold, Rhaleb Zayer, and Hans-Peter Seidel. 2005. Mesh segmentation driven by Gaussian curvature. *The Visual Computer* 21, 8 (2005), 659–668.