Computational Design of Nebuta-like Paper-on-Wire Artworks

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Abstract

This paper presents an algorithm for designing Nebuta-like paper-on-wire artworks, artifacts made with multiple pieces of paper and wireframes inside. The algorithm takes a 3D model as input and generates a wireframe that can be easily covered with paper patches. To do so, we first modified and applied an existing algorithm for garment pattern generation to extract both the wireframe structure and the segmented patches from the 3D model. In doing so, our algorithm ensures that each patch is nearly developable so that each patch can be made with paper. We also approximate each patch to a developable surface and flatten it to produce a two-dimensional pattern. The algorithm's effectiveness is demonstrated through numerical experiments and by successfully fabricating two examples.

Background

Nebuta is an illuminated float made by covering a wireframe with brightly colored and painted paper, which is used in festivals in Aomori, Japan. The design of the wireframe structure is challenging because one needs to balance the aesthetic goal and fabrication costs. This requires a level of artisanal skill that can only be honed through decades of experience; therefore, it is difficult for novices to master. To address this issue, we propose a computational pipeline for designing Nebuta-like paper-on-wire artworks.

Figure 2. a Nebuta exhibited in the 2012 Asamushi Onsen Nebuta Festival © 663highland, licensed under CC-BY. https://commons.wikimedia.org/wiki/File:Asamushi_Onsen_Nebuta_Matsuri_Aomori_Japan06n.jpg

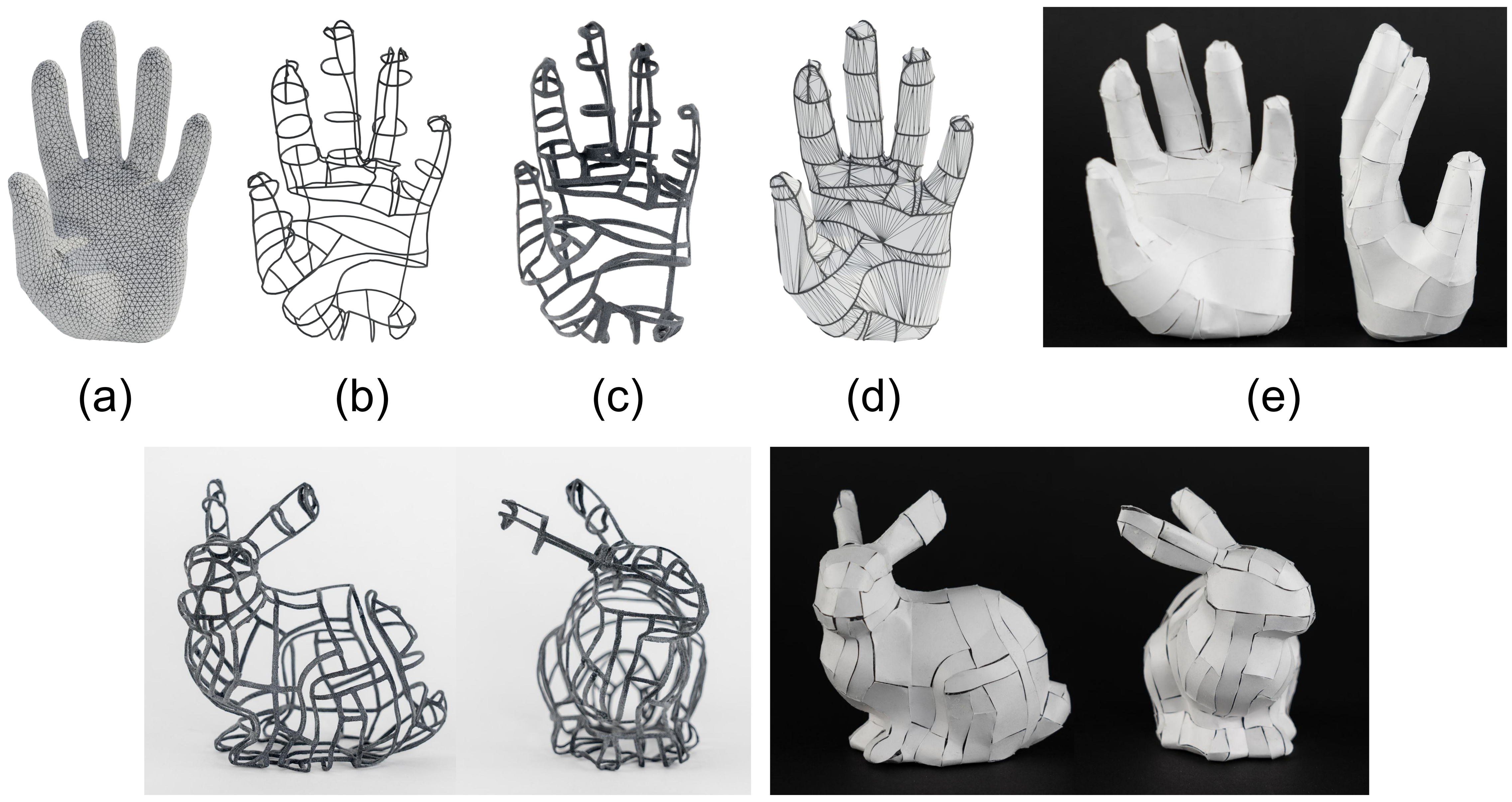

***Figure 1.** Our method takes a 3D model (hand) as the input (a), extracts the 3D wireframe (b) and computes the corresponding 2D pattern. (c) is the 3D printed plastic wireframe; (d) is the approximated developable patches; (e) is the fabricated model from two viewpoints using washi paper. Two images at the bottom show another fabrication result of the bunny model.*

Method

Our method takes a surface mesh as input and utilizes the garment segmentation algorithm of [Pietroni et al. 2022] to extract wires and patches. After the segmentation, we approximate each patch into triangle strips and flatten it.

While the original method ensures each segmented patch's textile-based distortion measure is below the threshold, we replaced the original distortion measure with a developability measure.

We define the developable measure as the one-sided discrete Hausdorff distance H_d between the original patch A and the approximated developable patch $\tilde{A}$ as follows:

$$H_d(A,\tilde{A}) = \max_{v \in A}(\min_{f \in \tilde{A}}(dist(v,f))$$

As for the developable approximation method, we first investigated [Mitani and Suzuki, 2004]'s method to produce the strip-based developable surface for each patch.

However, we found that their algorithm sometimes produces sharp creases and degenerate triangles due to its greedy search approach, as shown in Figure 3 middle. We thus propose a dynamic programming-based algorithm that considers all triangulation possibilities.

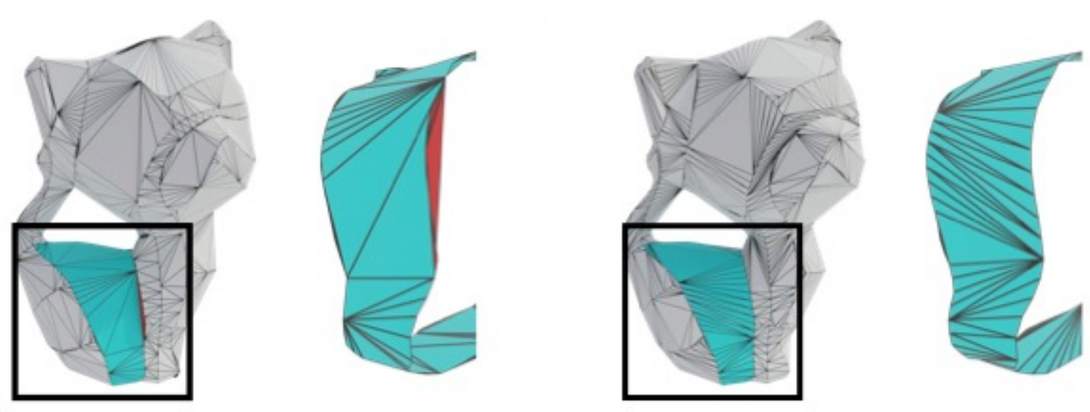

***Figure 3.** Our developable approximation method. For a given 3D shape, [Mitani and Suzuki 2004] can generate sharp creases in the approximated patch (left, creases shown in red from a different viewpoint), while our method can avoid such creases (right).*

Results

We evaluated the material costs on five models from the dataset in [Pietroni et al., 2021] and compared the results with those obtained using our method, the [Pietroni et al., 2022]'s original method, and our method with [Mitani and Suzuki, 2004]'s greedy method for developable approximation. To compare the effect on the number of patches while keeping the approximation error constant, we carefully selected the threshold so that the approximation error is in the range of [0.022, 0.026]. We summarized the result in Table 1. The result shows that compared to the baseline or the greedy method, the proposed method achieves a similar approximation error with fewer patches and shorter wire lengths on average.

We also fabricated two models (hand and bunny), as shown in Figure 1.

Table 1: Experiment Results.

	Patch Number ↓			Wire Length ↓		
Model	Ours	Baseline	Greedy	Ours	Baseline	Greedy
foot	**18**	39	21	**7.3**	9.7	8.3
3 holes	**36**	82	40	**20.9**	28.0	24.1
hand	54	98	**51**	**16.4**	22.0	16.5
cow	78	140	**74**	**25.5**	32.7	26.4
bunny	**70**	236	80	**28.4**	48.3	30.1
AVG	**51.2**	119.0	53.2	**19.7**	28.0	21.1

Future Works

For future work, one can aim to further optimize the wireframe by taking the texture and lighting conditions into account. This will ensure an aesthetically appealing illuminated texture while preventing the shadow of the wire from being cast outward.

References

1. Jun Mitani and Hiromasa Suzuki. 2004. Making Papercraft Toys from Meshes Using Strip-Based Approximate Unfolding. ACM Trans. Graph. 23, 3
2. Nico Pietroni, Corentin Dumery, Raphael Falque, Mark Liu, Teresa Vidal-Calleja, and Olga Sorkine-Hornung. 2022. Computational Pattern Making from 3D Garment Models. ACM Trans. Graph. 41, 4
3. Nico Pietroni, Stefano Nuvoli, Thomas Alderighi, Paolo Cignoni, and Marco Tarini. 2021. Reliable Feature-Line Driven Quad-Remeshing. ACM Trans. Graph

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