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

Naoki Agata
agata-naoki668@g.ecc.u-tokyo.ac.jp
The University of Tokyo
Japan

Anran Qi
annranqi1024@g.ecc.u-tokyo.ac.jp
The University of Tokyo
Japan

Yuta Noma
noma@akg.t.u-tokyo.ac.jp
The University of Tokyo
Japan

I-Chao Shen
ichaoshen@g.ecc.u-tokyo.ac.jp
The University of Tokyo
Japan

Takeo Igarashi
takeo@acm.org
The University of Tokyo
Japan

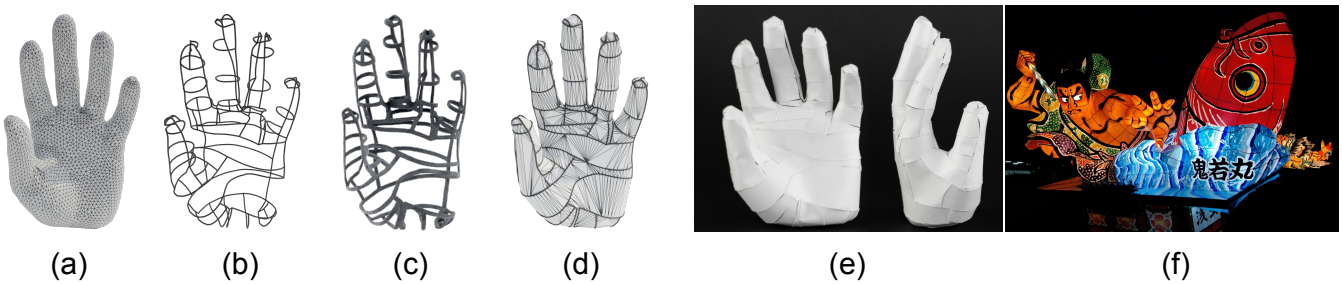


Figure 1: Our method takes a 3D model as the input (a), extracts the 3D wireframe (b) and computes the corresponding 2D pattern. (c) is the 3D printed plastic wireframe; (d) is the approximated developable patches; (e) is the fabricated model from two viewpoints using washi paper; (f) shows a Nebuta exhibited in the 2012 Asamushi Onsen Nebuta Festival © 663highland, licensed under CC-BY.*

ACM Reference Format:
Naoki Agata, Anran Qi, Yuta Noma, I-Chao Shen, and Takeo Igarashi. 2023. Computational Design of Nebuta-like Paper-on-Wire Artworks. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Posters (SIGGRAPH '23 Posters), August 06-10, 2023.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3588028.3603655

1 INTRODUCTION

Nebuta is an illuminated float made by covering a wireframe with brightly colored and painted paper, which is exclusively used in festivals in Aomori, Japan (Figure 1(f)). 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. We formulate aesthetics as shape similarity between the output piecewise developable patches and the input shape, and the fabrication cost as the number of developable pieces formed by the wire.

Existing developable approximation works either do not form a patch layout (e.g., [Binninger et al. 2021]) or do not encourage orthogonality of the wire crossing (e.g., [Zhao et al. 2022]). We thus have built our method upon the garment pattern generation algorithm proposed by [Pietroni et al. 2022]. Their approach employed a 3D garment surface shape as input and generated the 2D pattern by segmenting the surface into patches using a textile distortion measure. In contrast, we applied a developable approximation measure to guide the segmentation process, considering that our target model consists of non-stretchable developable paper patches rather than stretchable textiles.

2 METHOD

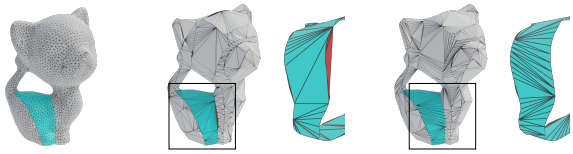
Our method takes a surface mesh as input and proceeds with three steps based on [Pietroni et al. 2022]: (1) cross-field construction, (2) layout construction, and (3) patch flattening. Step 1 encourages the orthogonal crossing of wires. Step 2 first inserts paths across the surface based on the cross-field, then iteratively removes the added paths. To ensure the producibility of the layout, we impose constraints such that each patch is topologically equivalent to a disk and has at most five corners. Finally, Step 3 performs patch flattening onto a plane. While Step 1 remains unchanged from the original method, we have modified Steps 2 and 3.

The original method utilizes the textile-based distortion measure, and Steps 2 and 3 work to minimize the measure. However, unlike fabric, paper cannot undergo non-isometric deformations such as stretching and shearing. Therefore, we made two technical contributions:

(1) We replaced the original distortion measure with the Hausdorff distance between the input surface and its developable approximation.

SIGGRAPH '23 Posters, August 06-10, 2023, Los Angeles, CA, USA

ACM ISBN 979-8-4007-0152-8/23/08.
https://doi.org/10.1145/3588028.3603655



[Mitani and Suzuki 2004] Ours

Figure 2: Our developable approximation method. For a given 3D shape (left), [Mitani and Suzuki 2004] can generate sharp creases in the approximated patch (middle, creases shown in red from a different viewpoint), while our method can avoid such creases (right).

(2) We introduced a new developable approximation algorithm that generates a triangulated strip that minimizes the Hausdorff distance.

Based on these two methods, in Step 2, We removed paths unless the approximation error of all patches remained below a heuristically predefined threshold. Also, we flattened each patch in Step 3 by recursively placing the developable approximation onto the plane without distortion. Below, we discuss the two contributions in detail.

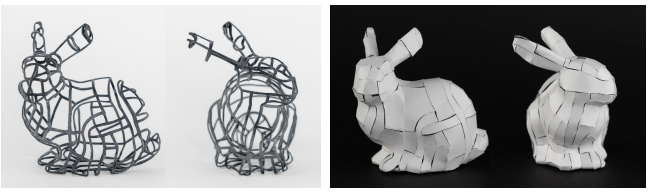


Figure 3: The 3D printed plastic wireframe (left) and the bunny fabricated with washi (right).

Hausdorff distance. We define the developable approximation error as the one-sided discrete Hausdorff distance H_d between the original patch A and the approximated developable patch $\hat{A}$:

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

where f denotes the triangle on the approximated developable patch $\hat{A}$ and v denotes the vertex the original patch A.

Developable approximation. 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 2 middle. We thus propose a dynamic programming-based algorithm that considers all triangulation possibilities. More specifically, we gradually increase the number of consecutive vertices on the wire of a patch and search the minimal one-sided Hausdorff distance for every possible triangulation with the memory of previous triangulation results. Finally, we obtain the triangulation of the developable approximation with the smallest one-sided Hausdorff distance.

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

3 RESULTS

We evaluated the material costs (i.e., patch number and wire length) on five models from the dataset in [Pietroni et al. 2021] and compared the results with those obtained using the original method, which served as our baseline for evaluation. Also, as an ablation study, we compared our results with those obtained using the greedy algorithm [Mitani and Suzuki 2004] for developable approximation while using the same Hausdorff distance measure. 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 $[0.022, 0.026]$.

Table 1 shows the result of the quantitative comparison. 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 and Figure 3, confirming that our pipeline produces visually pleasing artifacts.

ACKNOWLEDGMENTS

We appreciate Yo Machita from the Hirosaki City Office for consulting and connecting with local Neputa artists and Koya Narumi for useful discussion. This work was in part supported by JST ACT-X JPMJAX200L, JST AdCORP JPMJKB2302, and JSPS Grant-in-Aid JP23K16921 and JP23KJ0582.

REFERENCES

Alexandre Binninger, Floor Verhoeven, Philipp Herholz, and Olga Sorkine-Hornung. 2021. Developable approximation via gauss image thinning. In *Computer Graphics Forum*, Vol. 40. Wiley Online Library, 289–300.

Jun Mitani and Hiromasa Suzuki. 2004. Making Papercraft Toys from Meshes Using Strip-Based Approximate Unfolding. *ACM Trans. Graph.* 23, 3 (aug 2004), 259–263. https://doi.org/10.1145/1015706.1015711

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, Article 157 (jul 2022), 14 pages. https://doi.org/10.1145/3528223.3530145

Nico Pietroni, Stefano Nuvoli, Thomas Alderighi, Paolo Cignoni, and Marco Tarini. 2021. Reliable Feature-Line Driven Quad-Remeshing. *ACM Trans. Graph.* 40, 4, Article 155 (jul 2021), 17 pages. https://doi.org/10.1145/3450626.3459941

Zheng-Yu Zhao, Qing Fang, Wenqing Ouyang, Zheng Zhang, Ligang Liu, and Xiao-Ming Fu. 2022. Developability-driven piecewise approximations for triangular meshes. *ACM Transactions on Graphics (TOG)* 41, 4 (2022), 1–13.