FoldingNet: From 2D Layout to 3D Model???

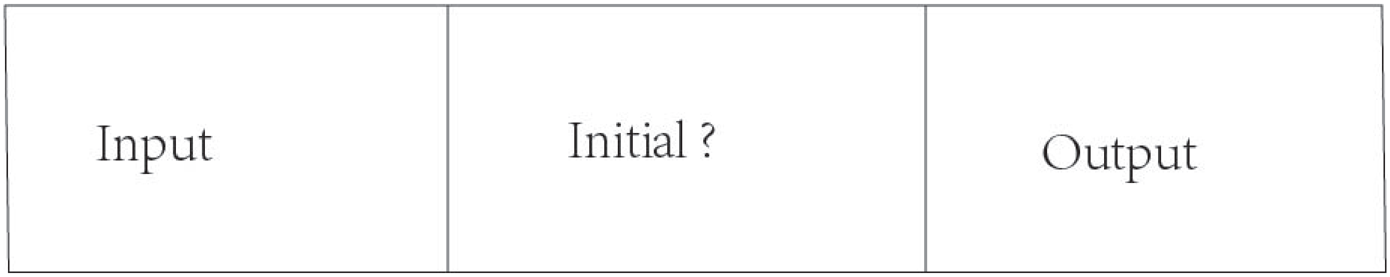

Figure 1: ***Overview.*** *(a) A given input layout (b) XX (c) final 3D model generated by our methods*

Abstract

In this paper, we will propose a new method for generating 3D models given its 2D layout, whose folded angels are learnt(?) by XX optimization.

Keywords: 3D Model?, XX

Concepts:

1 Introduction

Cartons have been widely used in packaging industry, to deliver various commodities including food items, daily necessities and electronic components. Instead of very basic packaging shapes like cubes, there exist multiple fantastic cartons to package wedding candies or take away coffee. These various designs increase much popularity, not to mention they're environment friendly due to their recycling and degradability.

Cartons are usually designed based on experience and trial-and-error? Depressingly, designers cannot see directly final model of carton when they are drawing its layout. Moreover, for non-experts, it's intractable to fold an irregular layout to final carton without instructions.

Researchers have studied paper folding problem for more than twenty years. It's been verified that given a net, i.e., a polygon and a set of creases, and the dihedral angles at each crease, we can know whether a polyhedron can be obtained in polynomial time. However, if the dihedral angles stay unknown, this problem becomes NP-hard even we simplify the 3D mdoel to orthogonal polyhedron whose dihedral angles are multiples of $\pi/2$ [Biedl et al. 2005].

However, the study above more focused on academic fileds, not on the applications of practical use.

Three-dimensional reconstruction has been wildly studied from different sources, such as point clouds, single images, and line drawings.

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2 Related Work

Reconsturction from single line drawings. Line drawings of three-dimensional objects have long been studied, and the main problem is still in reconstruction given projection on two-dimensional planes. Some researchers treat this task as optimization problem. [Marill 1991] proposed MSDA(Minimize the Standard Deviation of Angles) principle to emulate the interpretion of line drawings as 3D objects. This new criterion is used by many other researchers later. [Leclerc and Fischler 1992] combined MSDA with the deviation from planarity as objective terms. [Cao et al. 2005] added symmetry measure of the objects to get more complicated results. Some other researchers try to solve this problem from the information theoretic point of view. [Marill 1992] minimized the description length of objects based on the idea that we usually pick the simplest one from infinite possibilities when we see the line drawing. [Shoji et al. 2001] implemented the principle of minimizing the entropy of angle distribution between line segments using genetic algorithm. Different from the input above, ours are expanded layout of three-dimensional objects in 2D planes, the lackness of 3D topology is main cencern in our problem.

Folding to polyhedron. [Lubiw 1996] provided an dynamic programming algorithm based on Aleksandrov's theorem to test whether a polygon can be folded into polyhedra which takes $O(n^2)$ time and space. [O'Rourke 2000] examined three open problems on the subject of folding and unfolding. [Biedl and Gen 2004] has studied in polynomial time to solve the question of when is the graph orthogonally convex polyhedra given a graph, edge length and facial angles, also shown that it's NP-hard to decide whether the graph is orthogonally polyhedra or not. Rather than given graph, [Biedl et al. 2005] proved that if given a net along with the dihedral angle at each crease, we can know whether a net can be folded to a polyhedron in polynomial time, but it becomes NP-hard without the angles even adding constrains on orthogonal polyhedron, which results in more difficultes on more complex input. Later, [Demaine and O'Rourke 2010] proposed a survey on the folding and unfolding in computational geometry. Compared to our desired result, polyhedron is a set of polygons without overlap, nevertheless, our 3D model contains paste faces that needs to be fixed to another panel. These works above justify our problem being harder to solve causing by even intricater inputs.

Paper craft. Various types of paper crafts have been studied in the field of computing and mathmatics. Origami is the Japanese traditional paper art of making different kind of objects by a single sheet of paper, and has been long studied since 1970s [Kanade 1980]. Lately, there have been newly researched automaticly generating a type of paper architecture named pop-ups. [Li et al. 2010] presented formulation of layouts, sufficient conditions to generate foldable and stable paper architectures, and proposed an automatic algorithm given any 3D models. Plenty papers studied this subject following the idea of Li's and make new improvements[Li et al. 2011] [Ruiz et al. 2013] [Le et al. 2014].

Motion planning of paper folding.

Laplace-Beltrami Eigenfunctions [Zhou et al. 2005] used the volumetric graph Laplacian to deform the 3D meshes while keeping the local details by encoding the difference between each point in the graph and the average of its neighbours. [Rustamov 2007] defined a robust deformation invariant representation named the GPS embedding based on the eigenvalues and eigenvectors of Laplace-Beltrami operators. [de Belen and Atienza 2016] generated the pipeline of skeleton extraction and skinning automatically, during skeleton extration they used GPS embedding to get a better result.

3 Optimization

3.1 Objective Term

Plane perpendicularity The adjacent planes should not be paralleled, and we encourage them to be perpendicular. The term used here is

$$\alpha_{pe} = \sum_{i=1}^{n} [\sin^{-1}(\mathbf{n}_1 \cdot \mathbf{n}_2)]^2, \quad (1)$$

where $\hat{n}_1$ and $\hat{n}_2$ denotes all possible combinations of normals of adjacent planes, and n is the number of such combinations.

Plane parallelism It was observed that two planes with same shape are probably paralleled, so we encourage more planes with same shape to be paralleled. The term is

$$\alpha_{pa} = \sum_{i=1}^{n} [\cos^{-1}(\mathbf{n}_1 \cdot \mathbf{n}_2)]^2, \quad (2)$$

where $\hat{n}_1$ and $\hat{n}_2$ denotes all possible combinations of normals of disadjacent planes that have same shape, and n is the number of such combinations.

3.2 CMA-ES

CMA-ES(Covariance Matrix Adaptation Evolution Strategy) is considered the state-of-the-art in evolutionary computation and is usually applied unconstrained or bounded constraint optimization problem.

Meanwhile, the input of our problem is the angle of each folding edge, and the value is in the field of $[0, 2\pi)$, so that our problem is also a bounded constraint optimization problem.

4 Experiment

We now describe the experimental part of our methods.

4.1 Implentation Details

Set the angle $\{\theta_i\}$ of each folding edge $\{\mathbf{e}_i\}$ as the input and $\{1, 1...1\}$ as initial value, we can easily compute the perpendicular term by replacing $\mathbf{n}_1 \cdot \mathbf{n}_2$ as $\cos\theta_i$ from Eq. 1, where θ_i is the dihedral angle of edge $\mathbf{e}_i$ whose adjacent planes have normal $\mathbf{n}_1$ and $\mathbf{n}_2$ separately.

Parallel term is computed by the normal of disadjacent planes which have same shape, here, we use same area of planes to define same shape. Meanwhile, we need to update the state of 3D model to calculate the current normals of planes in each iteration, which is actually time consuming.

4.2 Results

5 User Study

6 Conclusion

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To all.

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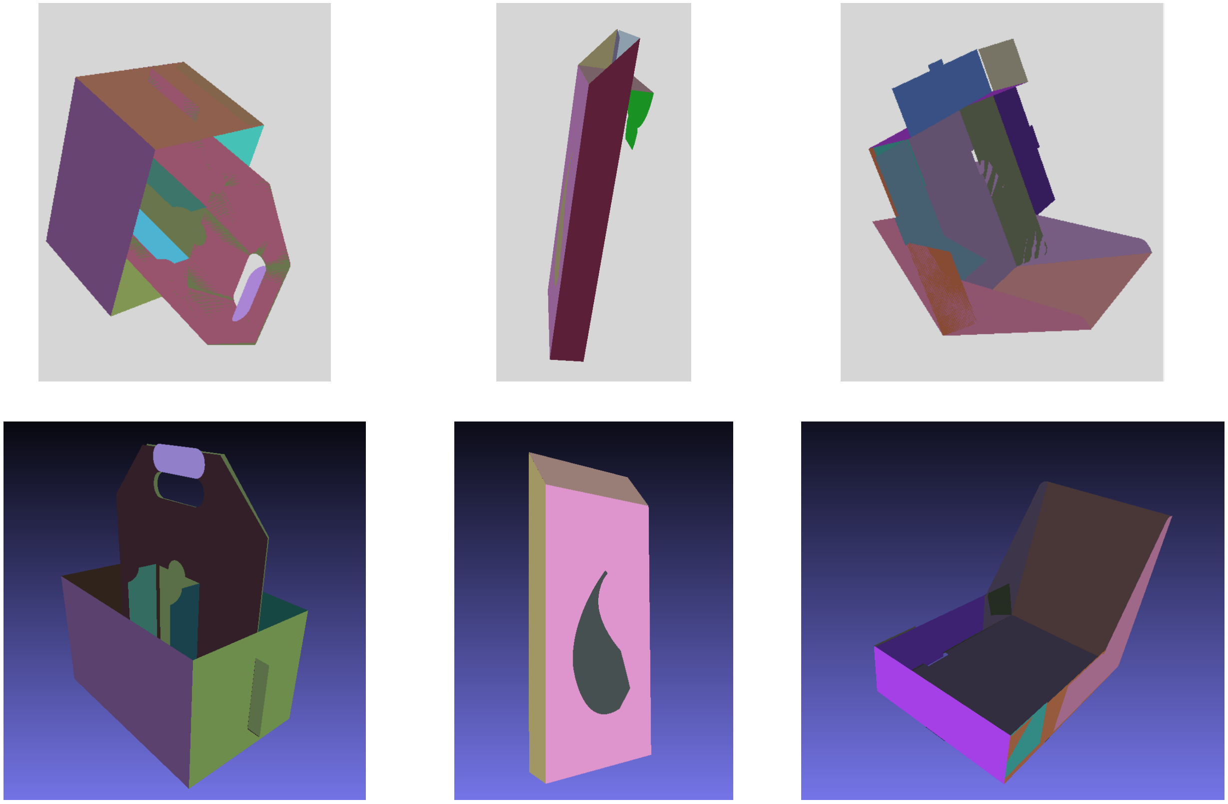

Figure 2: *Three models optimized by perpendicular term*

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