Digital 3D Smocking Design

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Smocking 🧼 not smoking!

https://www.pinterest.ch/pin/690669292878820301/
https://www.pinterest.ch/pin/1002332460800168804/
https://www.pinterest.ch/pin/574560864973414366/
British garment “Smocc”

https://collections.vam.ac.uk/item/O954665/harrowing-with-oxen-print-unknown/

https://collections.vam.ac.uk/item/O57071/national-photographic-record-and-survey-photograph-stone-benjamin-sir/
From “Smocc” to Smocking

https://collections.vam.ac.uk/item/O354402/smock-smock-unknown/

https://collections.mfa.org/object/482317

https://collections.vam.ac.uk/item/0138699/vivienne-fashion-doll-latter-axton-jap/
English smocking

- folded pleats
- gathered threads
- embroidered visible stitches
Canadian smocking

- Stitching lines annotated on the back
- Invisible stitches
- Geometric textures from folds
Canadian smocking

- invisible stitches
- contracting stitches together
- geometric textures from folds
Canadian smocking

invisible stitches

geometric textures from folds

front view
Our goal: smocking preview

input smocking pattern

after stitching

output smocked result
Smocking: easy to formulate

Smocking pattern

- graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$
- stitching lines $\mathcal{L} = \{\ell_i\}$

For example:

- $\ell_1 = (v_{0,1}, v_{1,2})$
- $\ell_2 = (v_{2,1}, v_{1,1})$
- $\ell_3 = (v_{4,1}, v_{3,2})$
- ...
... but not easy to solve

\[ \bar{e}_{25} = 2.69 \text{ cm} \]
\[ \bar{e}_{50} = 1.26 \text{ cm} \]
\[ \bar{e}_{75} = 0.97 \text{ cm} \]

cloth simulation using Blender

- geometry is unknown before smocking
- no geometry priors \(\rightarrow\) irregular pleats
How to extract geometric priors?

- merge each **stitching line** into a single node
- delete **degenerated & redundant edges**

✓ sewing constraints hard-coded
... capture modified geometry?

- fabric shrinks during the smocking process!

- back view

- front view

smocked graph
✓ sewing constraints
hard-coded
✗ modified geometry
not considered!
Embedding distance constraint

- $\ell_i$ is embedded at $x_i \in \mathbb{R}^3$
Embedding distance constraint

- $\ell_j$ is embedded at $x_j \in \mathbb{R}^3$
Embedding distance constraint

- $\ell_i$ is embedded at $x_i \in \mathbb{R}^3$
- $\ell_j$ is embedded at $x_j \in \mathbb{R}^3$
Embedding distance constraint

- $\ell_i$ is embedded at $x_i \in \mathbb{R}^3$
- $\ell_j$ is embedded at $x_j \in \mathbb{R}^3$

⚠️ $\|x_i - x_j\| \leq 1$

- If $\|x_i - x_j\| > 1$, fabric would tear at ‼️
$d(\cdot, \cdot)$: the distance in original fabric

$\|x_i - x_j\| \leq d_{i,j}$ where $d_{i,j} = \min_{v_p \in \ell_i, v_q \in \ell_j} d(v_p, v_q)$

$v_i$ is embedded at $x_i \in \mathbb{R}^3$
Embedding distance constraint

\[ \|x_i - x_j\| \leq d_{i,j} \quad \forall i, j \]

- \(d_{i,j}\) encodes the modified geometry
- guarantees that the fabric won’t tear after stitching

**goal** find an embedding that satisfies all the constraints 😊

**problem** trivial solutions such as \(\forall i \quad x_i = (0,0,0)\) are feasible 😞
Observations

valid but cluttered result

expected result
Our formulation for smocking

\[ \max_{\mathbf{x} \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\| \]

s.t. \[ \|x_i - x_j\| \leq d_{i,j} \quad \forall i \neq j \]

energy avoids cluttered (trivial) solutions

constraints fabric doesn’t tear after smocking

challenges
- non-convex problem
- \( n(n-1)/2 \) constraints, too many!
… are all constraints necessary?

$$\max_{X \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\|$$

s.t. $$\|x_i - x_j\| \leq d_{i,j} \quad \forall i \neq j$$

**equivalent setting**

- a set of balls can move around
- fragile string connecting balls with length $$d_{i,j}$$

⚠️ $$s_2$$ will break before $$s_1$$ is pulled taut
Simplified formulation

\[
\max_{x \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\| \\
\text{s.t.} \quad \|x_i - x_j\| \leq d_{i,j} \quad \forall i \neq j
\]

energy avoids cluttered (trivial) solutions

constraints fabric doesn’t tear after smocking

\[
\|x_i - x_j\| \leq d_{i,j} \quad \forall (i, j) \in \mathcal{E}
\]

Only check the vertices that are adjacent
Unconstrained formulation

\[
\max_{x \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\| \\
s.t. \, \|x_i - x_j\| \leq d_{i,j} \quad \forall (i, j) \in \mathcal{E}
\]

reformulate

\[
\min_{x \in \mathbb{R}^3} \sum_{(i,j) \in \mathcal{E}} (\|x_i - x_j\| - d_{i,j})^2
\]

graph embedding problem
Motivations

Smocked result = underlay + pleat

Height map visualization
... categorize vertices!

**underlay vertex**

**pleat vertex!**
Methodology: underlay graph

smocking pattern

smocked graph

underlay subgraph \((\mathcal{V}_u, \mathcal{E}_u)\)
Methodology: pleat graph

smocking pattern

smocked graph

pleat subgraph \((V_p, E_p)\)
Methodology: two-stage solver

$$\min_{x \in \mathbb{R}^2} \sum_{(i,j) \in \mathcal{E}_u} \left( \|x_i - x_j\| - d_{i,j} \right)^2$$
Methodology: two-stage solver

\[
\min_{x \in \mathbb{R}^2} \sum_{(i,j) \in \mathcal{E}_u} (\|x_i - x_j\| - d_{i,j})^2
\]

\[
\min_{x \in \mathbb{R}^3} \sum_{(i,j) \in \mathcal{E}_p} (\|x_i - x_j\| - d_{i,j})^2
\]
Methodology: ARAP-deformation

As-rigid-as-possible surface modeling, Sorkine and Alexa, SGP 2007
Our results vs. fabrications

smocking pattern

ours

fabrication
Our results vs. fabrications

smocking pattern

ours

fabrication
Our results: radial grid

smocking pattern
front
back
Our results: hexagonal grid
Our results vs. Marvelous Designer
Our results vs. ArcSim


✓ correct aspect ratio after smocking  ❌ non-realistic pleats
Our results vs. C-IPC

[C-IPC] “Codimensional Incremental Potential Contact”, Li et al. ACM Transactions on Graphics (TOG), 2021

✓ correct aspect ratio after smocking
✓ reasonable but not very accurate pleats
✗ computationally expensive
✗ non-trivial parameters tuning
Limitations & future work

No collision handling: self-intersections
Limitations & future work

Geometric features vs. material-dependent features

- canvas
- polyester (crisp, thin)
- polyester (soft, thick)
- satin
- ours
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Supplementary slides
Methodology: two-stage solver

\[
\min_{x \in \mathbb{R}^2} \sum_{(i,j) \in \mathcal{E}_u} (\|x_i - x_j\| - d_{i,j})^2
\]

\[
\min_{x \in \mathbb{R}^3} \sum_{(i,j) \in \mathcal{E}_p} (\|x_i - x_j\| - d_{i,j})^2
\]
Embedding distance constraint
Methodology: two-stage solver

- Faster convergence
- Better local minima
- More realistic results

![Graph showing two stages of solver](image1.png)

![Comparison of front and back views of pleat](image2.png)
Our results

pattern

front

back
Our results vs. fabrications
Observations: Underconstrained Pattern

\[ d_{1,2} = 1, d_{2,3} = 1, d_{1,3} = \sqrt{2} \]

We can embed \( \ell_i \) at \( x_i \) such that:
\[ \| x_i - x_j \| = d_{i,j} \]

\[ d_{1,2} = 1, d_{2,3} = 1, d_{1,3} = \sqrt{5} \]

We have:
\[ \| x_1 - x_3 \| \leq d_{1,2} + d_{2,3} = 2 \]
\[ < d_{1,3} = \sqrt{5} \]
Observations: Overconstrained Pattern

Impossible to embed $v_i$ at $x_i \in \mathbb{R}^2$ such that:

$$||x_i - x_j|| = d_{i,j}$$

Well-constrained example
... are all constraints necessary?

\[
\max_{x \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\| \\
\text{s.t. } \|x_i - x_j\| \leq d_{i,j} \forall i \neq j
\]

equivalent setting

- a set of balls can move around
- fragile string connecting balls with length \(d_{i,j}\)

\(s_2\) will break before \(s_1\) is pulled taut
Methodology: two-stage solver

\[
\min_{x \in \mathbb{R}^2} \sum_{(i,j) \in \mathcal{E}_u} (\|x_i - x_j\| - d_{i,j})^2
\]

\[
\min_{x \in \mathbb{R}^3} \sum_{(i,j) \in \mathcal{E}_p} (\|x_i - x_j\| - d_{i,j})^2
\]