Quasi-Developable Garment Transfer for Animals

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Figure 1: Garment transfer results generated by our method: (left) input character bodies: (middle & right) character bodies outfitted with a garment transferred from the human at the center of each image to a variety of other characters.

ABSTRACT

In this paper, we present an interactive framework to model garments for animals from a template garment model based on correspondences between the source and the target bodies. We address two critical challenges of garment transfer across significantly different body shapes and postures (e.g., for quadruped and human); (1) ambiguity in the correspondences and (2) distortion due to large variation in scale of each body part. Our efficient cross-parameterization algorithm and intuitive user interface allow us to interactively compute correspondences and transfer the overall shape of garments. We also introduce a novel algorithm for local coordinate optimization that minimizes the distortion of transferred garments, which leads a resulting model to a quasi-developable surface and hence ready for fabrication. Finally, we demonstrate the robustness and effectiveness of our approach on a various garments and body shapes, showing that visually pleasant garment models for animals can be generated and fabricated by our system with minimal effort.

CCS CONCEPTS

•Computer methodologies → Mesh Geometry Models;

KEYWORDS

Garment modeling Interactive correspondence mapping Developable optimization

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1 INTRODUCTION

Modeling of real or virtual garments is a necessary component of many computer graphics animation and applications [zoo 2017]. Recent commercial software packages such as Marvelous Designer, provide assistance in interactive modelling and editing 2D garment patterns. Based on 2D garment patterns, a 3D garment modeling process typically includes (1) placing garments on a mannequin, (2) running cloth simulations, (3) adjusting various 2D patterns and parameters, and (4) repeating the process until the model is deemed complete. This process must be repeated until the designer is satisfied, making 3D garment modeling remain an unintuitive and time-consuming process. Given the above, we are motivated by these problems when contemplating the current 3D garment modeling process. Sculptural techniques that transfer existing garment models to target characters have been shown to deliver high-quality modeling [Brouet et al. 2012; Lee et al. 2013; Meng et al. 2012; Wang et al. 2007, 2005]. For garment transfer between relatively similar body shapes, various techniques have been proposed. In particular, Meng et al. [2012] and Brouet et al. [2012] apply the source garment configurations to coarse transferred results and their methods preserve the detail of the source garment with developability. Although this is useful in many cases, it is not trivial for these techniques to generate garments for characters with large deformations because the proposed transfer methods assume the variation of shapes and poses are sufficiently small. These previous methods also require pre-defined correspondences, which become ambiguous in case of different type of characters.

To address the problems above, we present a system that creates a high-quality garment model for various characters from a single template model. In summary, our primary contributions are as follows:

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Figure 2: Illustrating coarse shape transfer in which users repeat three steps (i.e., interactive cross-parameterization, scale-aware garment transfer, and user editing) until the transferred garment model is complete and acceptable.

- A framework to generate developable versions of existing garments for target characters whose proportions and body shape significantly differ from those of source characters.
- An interface that allows users to interactively add correspondence points and check the accuracy of the transferred results.
- A novel garment refinement algorithm that generates developable garment models based on local shape analysis that is resilient to large shape variations.

2 RELATED WORK

In this section, we describe works related to the automatic generation of 3D garments on various characters. Given input characters, a warping process is generally first applied to a generic garment model using heuristic correspondences between source and target characters [Brouet et al. 2012; Lee et al. 2013; Meng et al. 2012; Wang et al. 2007, 2005]; however, these approaches tend to generate a garment model that overfits along character bodies with a non-developable surfaces, resulting in an increased involvement of Gaussian curvatures in producing garments [Wang et al. 2007, 2005]. Previously, the problem of large deformations between target characters is effectively addressed using a set of normal vectors of the given template model [Brouet et al. 2012; Meng et al. 2012]. Here, outputs have a low distortion mapping to a set of 2D patterns, enabling texture mapping and actual manufacturing. Unfortunately, these approaches are limited to characters which are posed with similar postures. In addition, Brouet et al. [2012] assume that the input character has pre-defined skeletal information. Narita et al. [2016] extend the garment transfer to generate various 3D target garments for biped or biceped characters. However, their method extracts the deformation that transforms a source character to a target character, so results tend to include a large distortion regarding geometry.

3 METHODS

3.1 Coarse Shape Transfer

We first deform a template garment model such that it fits a target body shape and posture. Given sparse annotations, we construct correspondences between a source and a target body. Based on the identified correspondences, the overall garment shape is then automatically transferred by using local coordinates, as described in [Wang et al. 2007].

3.1.1 Interactive Cross-Parameterization. Unlike garment transfer approaches for the human body, it is challenging to automatically extract correspondences across different types of animals, as the definition of dense correspondences here is ambiguous. Therefore, our system allows users to interactively build correspondences with sparse key point annotations (in our experiments, we use 19 points) by adopting the cross parameterization method proposed by Aligerman et al. [2014]. These key points are selected based on anatomical semantics (i.e., elbows, shoulders, and so on.). Although the original paper involves time-consuming second-order cone programming, in this paper, we simplify the approach using linear least-square optimization to achieve interactive performance. We briefly explain the key idea and highlight the modifications that we make. The system takes a set of vertices on the meshes as an input, and then follows the three steps: (i) cut the two meshes into consistent pairs of disks; (ii) jointly flatten each pair of two disks to minimize isometric distortions while guaranteeing local injectivity; and (iii) compute a continuous bijective map that is consistent with the flattening. In this paper, we use a Laplacian with a mean value coordinate on 2D unit square $\{(u, v) | 0 \leq u \leq 1, 0 \leq v \leq 1, u, v \in \mathbf{R}\}$, where the curve vertices are set as boundary constraints.

3.1.2 Scale-Aware Garment Transfer. Once the correspondences are built, the next step is to transfer garment templates to a target character based on the correspondences. In this paper, we use a garment transfer method based on local coordinates in spirit to [Wang et al. 2007]. Note that the global scales of a source and a target body are first normalized using bounding boxes. In particular, we define local coordinates of the source garment vertices by using k -nearest polygons on the source body, and use these coordinates for mapping the template garments to the target body. This is called polygon driven Free-Form Deformation (p-FFD). Please refer to Wang et al. [2007] for more details.

3.1.3 User Editing. The transferred results may lack accuracy when using the correspondences between characters based only on the given boundary constraints. Users then interactively add the 3D landmarks on each character’s corresponding surfaces. The corresponding map with boundary constraints can be updated according to these additional points to improve the coarse transferred shape. This step is fast enough to support interactive garment design because it only requires solving a sparse linear least-square problem.

3.2 Refinement

After transferring the overall garment shape to the target character, we refine the underlying vertex positions such that the resulting garment is quasi-developable (i.e., as developable as possible). The key challenge here is that simply constraining vertex positions to be on a quasi-developable surface could result in lack of distinctive characteristics of the garments (e.g., frills and drapes). Therefore, it is vital to consider the design of garments while constraining developability. Though Brouet et al. [2012] obtain developable garment models by constraining deformed triangles to be as affine as possible, it is not trivial to apply their approach when poses and shapes largely vary. Therefore, we instead propose a refinement method based on local coordinate analysis that is resilient to large shape variations.

3.2.1 Rotational Normalization. To minimize the effect of rotations across characters, we first align each part of the garments (see Figure 3). We assume that a garment G consists of assembled patches M_i , which is two manifolds in the form of a piecewise linear triangular mesh (i.e., $G = M_1 \cup M_2 \cup \dots \cup M_n$). Let us then define several points on the garment patch using the farthest point sampling method to ensure a fast computation. Here we formulate the following rigid shape-matching system to compute a set of the optimal rotation matrix R_i :

$$\arg \min_{R_i} \sum_{\mathbf{p}_{i,j} \in M_i} \|R_i(\mathbf{p}_{i,j} - \mathbf{c}_i) - (\mathbf{p}'_{i,j} - \mathbf{c}'_i)\|^2 \quad (1)$$

where $\mathbf{p}_{i,j}$ and $\mathbf{p}'_{i,j}$ are the j -th positions on a patch M_i of the source model and the coarse transferred model, respectively, and $\mathbf{c}_i, \mathbf{c}'_i$ are the centers of mass of the source garment part and that of the coarse transferred garment parts.

3.2.2 Shape Relaxation. Inspired by the optimization proposed by Brouet et al [2012], we propose the following energy function to preserve the original surface details without compromising developability:

$$E = E_s + E_f + E_d \quad (2)$$

$$\text{subject to } \mathbf{v}_s = \mathbf{v}_{s'} \quad \mathbf{v}_s, \mathbf{v}_{s'} \in V_{seam}.$$

where E_s is the as-2D-as-possible deformation term for each patch rotational normalization, E_f is the Laplacian term, E_d is a damping term, V_{seam} is the set of constrained vertices (including all the seam line vertices), and $\mathbf{v}_s$ and $\mathbf{v}_{s'}$ are the vertices of the respective sets that correspond to one another in a one-to-one relation.

Let $\mathbf{p}_i, i \in \{1, 2, 3\}$ be the triangle vertices, and we compute a fourth vertex by offsetting $\mathbf{p}_1$ via the triangle normal. Next, we define the local triangle frame of t -th triangle $P^t = (\mathbf{p}_4 - \mathbf{p}_1, \mathbf{p}_4 - \mathbf{p}_2, \mathbf{p}_4 - \mathbf{p}_3)$. The gradient from the source to the target garment can then be formulated as

$$E_s = \sum_G \sum_{t \in M_i} \|\tilde{P}^t (R_i P^t)^{-1} - R_i T^t\|_F^2 \quad (3)$$

where $\tilde{P}^t$ is the local frame after the deformation, R_i is the rotational matrix of the garment patch M_i ; (see Section 3.2.1) and $\|\cdot\|_F$ is the Frobenius norm for matrices, and T^t is the target triangle gradients.

To enforce the smoothness on the mesh, we also add the Laplacian term [Wang 2008]

Figure 3: Illustrating how source garment patches are matched to the transferred patches; next, the transferred model is updated using the triangle normal of the matched source garment patch and rotation matrix R .

$$E_f = \lambda \sum_{i \in V} \|\mathbf{v}_i - \frac{1}{N_i} \sum_{j \in N_1(i)} \mathbf{v}_j\|^2 \quad (4)$$

where $\mathbf{v}_j$ denotes the 1-ring neighbor of $\mathbf{v}_i$; N_i is the number of 1-ring neighborhood vertices of $\mathbf{v}_i$, and λ is a weight value.

The third term is a damping term, defined as

$$E_d = \sum_i w_i \|\mathbf{v}_i - \mathbf{v}_i^0\|^2 \quad (5)$$

where $\mathbf{v}_i$ denotes the deformed vertices and $\mathbf{v}_i^0$ is the initial position of the vertices of the coarse transferred model. The damping effect is differentiated based on corresponding body parts [Zeng et al. 2012] (as shown Figure 3).

To avoid self-intersection after transfer, we first minimize the energy function in Equation (2) with no collision constraints, and then iteratively introduce collision-resolving constraints, and repeat the optimization using the collision avoidance proposed by Guan et al. [2012]. In addition, we employ the developable optimization function [Jung et al. 2015] to help us achieve a better balance between preserving the garment silhouettes and delivering developability.

3.3 2D Pattern Generation

2D pattern generation techniques could be classified as ABF++ approaches [Brouet et al. 2012; Jung et al. 2015] and As-Rigid-As-Possible deformation (ARAP) approaches [Bartle et al. 2016; Meng et al. 2012]. In this paper, we employ an ARAP-based system as it balances length and angle preservation.

4 RESULTS

The garments transferred via our system are successfully applied to various garment models of both biped and quadruped characters (see Figure 1). We also demonstrate that our system preserves the original design of the garments without compromising the developability. Further, the results show that our approach can be applicable to complex garments such as skirts.

4.1 Validation.

We validate our approach by fabricating a garment for a 3D printed cat model (see Figure 4). The resulting garment fits the shape of the cat model without unpleasant distortion or wrinkles, which does not exist in the source garment.

Figure 4: Validating our approach by generating a real garment: here, we transferred a tank-top model to 3D prints.

4.2 Comparison.

Figure 5 shows (a) the transferred results of the method proposed by Wang et al. [2007] (without scale adjustments), (b) our course transferred results with the refinement technique proposed by Zeng et al. [2012], which Li and Lu [2014] use for quasi-developable approximations, and (c) our method. Our approach can provide more plausible garment models of the target characters while preserving the original design and constraining the developability. Further, we compare our results to the method proposed by Narita et al. [2016]. The previous method greatly depends on the number of the user-specified points to achieve the correspondence between characters, so we defined about 130 user-specified points to generate this horse garment. To preserve the design of its hem, they project the vertices of boundaries to the least-square plane. Consequently, their method could produce overtight and unnatural-looking garments. In contrast, our system requires only 32 points (consisting of 19 boundaries and 13 inner points) to obtain the correspondence map. Besides, our garment approach fits the target characters with smaller Gaussian curvatures (See Fig. 6). Note that, to compute the Gaussian curvature of a mesh, we employed the criteria introduced by Zeng et al. [2012]. Additionally, our method achieves smoother mesh deformation because of the Laplacian term in the optimization.

4.3 Limitation and Future Work.

Although our proposed system can control a wide range of garment designs, it has problems connecting garment patches, i.e., seam regions. The key limitation here is its sensitivity to setting the source garment patches because our system does not change the number of patches as it transfers from one model to another. In the future, we plan to implement a segmentation function that can divide a source garment into an optimal number of patches suitable for a given target model [Julius et al. 2005]. The output quality is also dependent on the quality of the cross-parameterization between characters.

5 CONCLUSION

In this paper, we propose a method to generate a garment model for various characters from a single template model. To identify the correspondence between a source and a target, we introduce an interactive framework for controlling the transferred results. Our system can thereby intuitively refine the location of corresponding points. Based on the dense correspondences, we can automatically

Figure 5: Comparing transferred result of the method proposed by (a) Wang et al. [2007], (b) Zeng et al. [2012] and (c) our method.

Figure 6: Comparing transferred result of the method proposed by (a) Narita et al. [2016] and (b) our method.

generate plausible garments for the target bodies while preserving the source garment design without losing its developability. In the future, we believe that our technique will open up a new venue for garment modeling and democratize costume design for manufacturing.

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