Flat Patterns from Curved Bodies

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Abstract

Starting from body scan data, we create a flat pattern for a skirt with non-traditional seams. We model the skirt with a surface in $\mathbb{R}^3$, cut up the surface into topological disks, and then use software developed by Sawhney and Crane to flatten the disks into pattern pieces in $\mathbb{R}^2$.

Introduction

Making garment patterns is fundamentally a question about geometry: how do we make a pattern out of flat fabric that will fit our 3-dimensional bodies which have variable curvature? Traditional patterns have features such as darts and pleats which alter the shape of the constructed garment. Using computational tools, we are interested in creating novel patterns by encompassing these features into long meandering seams. The goals of this sort of pattern-making are two-fold; well-designed seams can be aesthetically interesting, and provide a good fit.

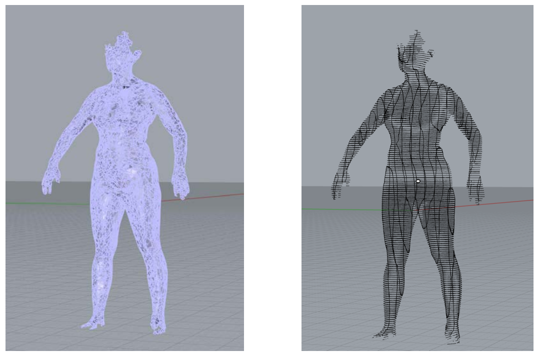
Figure 1: *Skirt Model*

In this paper, we describe the design and construction method for a *knee-length mermaid skirt*. This skirt was chosen since its cross sections are simple closed curves, making it straightforward to model (see Figure 1), and has points of both negative and positive curvature. Starting from 3D body scan data, we constructed a digital model in $\mathbb{R}^3$ of a skirt to fit an individual. To construct our flat pattern we began by drawing the desired pattern on the skirt surface, then used software developed by Sawhney and Crane [4] to create a flat pattern. It is interesting to note that our approach to design is similar in spirit to a method of pattern making popularized by designer Shingo Sato, called *Transformational Reconstruction* (TR). In this method, the designer makes a garment of the desired shape out of an inexpensive material such as muslin. Then, by drawing directly on the garment, a new pattern is traced out, which is then cut and flattened onto the material that will make the final garment. The TR process and final garments are works of art. We encourage the reader to see [2] for images of the TR process.

Modeling a Skirt

Traditionally when measurements are taken to develop a pattern, the pattern-maker relies on their ability to identify landmarks such as bust, waist, hips, etc. to draw a polygon which is used as the basis "size" for the pattern shape. Meanwhile, the pattern features that influence the "shape" of the garment (i.e. darts, pleats, curves) are placed intuitively and then refined through a series of prototypes until the designer is satisfied with both fit and aesthetic.

Our approach to pattern development attempts to bypass designer intuition by building a model of the final garment directly from the body scan. Using a Human Solutions VitusXXL 3D Body Scanner, we scanned one 47-year-old white female. We then imported the quad mesh into Rhino and used a series of cleaning commands to create a "watertight" mesh. Once the model is watertight, the Rhino command "contour" allows us to trace the mesh in a direction defined by a construction plane; for our skirt surface, we chose to contour in the z-direction. These traces act as landmarks providing body dimensions and are the curves used to build the surface. To properly extract information and manipulate the contours, these curves must be simple and closed.



(a) **(b)**

Figure 2: *(a) watertight mesh (b) contours taken in both y & z directions*

The *knee-length mermaid skirt* requires the shape to be form-fitting until the mid-thigh then gradually become more negatively curved. Therefore to build the top half of the skirt, we used the cleaned contour curves from the body scan data above the mid-thigh. From the last contour at mid-thigh, we constructed ellipses that gradually scaled larger until the mid-calf landmark was reached. In traditional pattern-making when working with non-elastic fabrics, it is customary to allocate some ease into patterns drafted from body measurements so the final garment is more comfortable for the wearer. To incorporate ease into the pattern, we offset our simple closed curves approximately a half-inch from the body scan mesh; as these curves were in horizontal level sets this was done by offsetting in the outward pointing normal direction. For the final step we lofted all the curves together resulting in the surface in Figure 1.

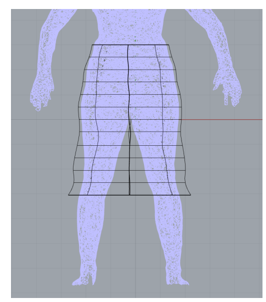


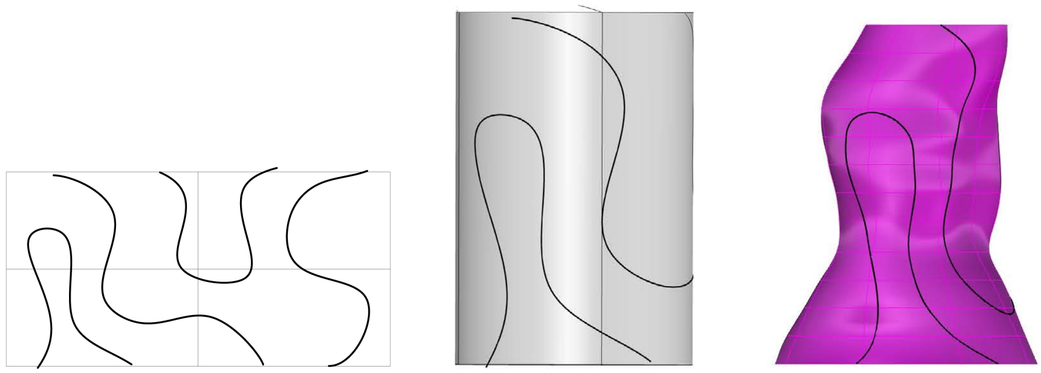
Figure 3: *Wireframe Skirt*

Designing the Pattern

The next step in the pattern construction was to cut the skirt surface into topological disks in $\mathbb{R}^3$. These disks were then mapped into the plane and formed the pattern pieces for the skirt. Our goal was to have a final garment with prominent aesthetically appealing seams. Also, we aim for very non-traditional seams which could invite questions about geometry.

The design for the pattern began on a flat rectangle with dimensions approximately equal to the length of the skirt, and the hip circumference. We drew a pattern on the rectangle and then wrapped the curves around a cylinder. We then aligned the cylinder with the skirt and radially projected the curves. After projecting, we *split* the surfaces along the curve to obtain meshes of the topological disks. Figure 4(a) shows the pattern we choose to explore in this paper, which is made of four such disks. We refer to this as the *lava lamp pattern*.

After splitting our surface, we used the Boundary First Flattening (BFF) program written by Sawhney and Crane [4] to map the disks into the plane creating our flat pattern pieces (see Figure 5). The BFF program maps a curved disk to the plane in a way that preserves boundary length and minimizes area distortion. (For

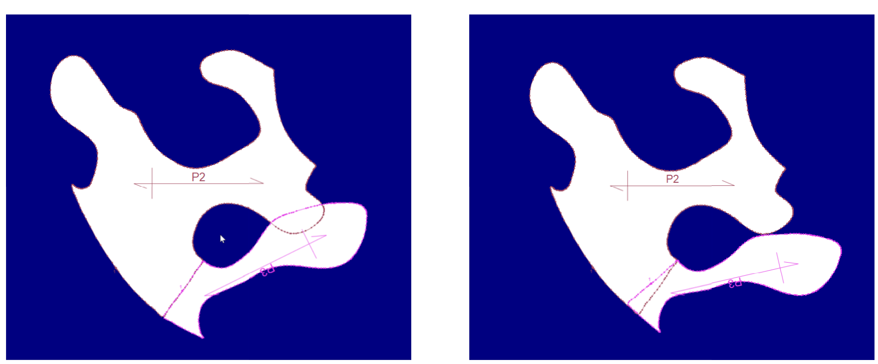


(a) (b) (c)

Figure 4: *(a) flat pattern (b) cylindrical pattern (c) projected to the skirt surface*

those interested, the area distortion is quantified by the Dirichlet energy, as described in [5].) The reader will note that these are exactly the properties needed to make pattern pieces for clothing. For example, it is essential that the boundary lengths are preserved, so that pieces that are to be sewn together have lengths that agree. An image of the flattened *lava lamp pattern* pattern pieces cut from fabric and ready for assembly is shown in Figure 6(a).

Besides aesthetics, we had several considerations when designing patterns. When flattening curved surfaces, distortion is greatest at places with high positive (bowl-shaped) or negative (saddle-shaped) curvature. To minimize area distortion, curves should go through places of high curvature. However, there is a trade off as these curves were more challenging to sew. We also aimed for our pattern pieces to have a relatively small *injectivity radius*. That is, we wanted the maximum radius of any disk contained in the pattern piece to be relatively small. Previous explorations (see [3] and [1]) in making curved surfaces from flat patterns revealed that constructions made from pattern pieces with small injectivity radius better approximated the target surface. Perhaps most importantly, it's essential for the flattening map to be a one-to-one map into the plane with sufficient space around the boundary for the seam allowance which is necessary for some construction methods.



(a) (b)

Figure 5: *(a) non-injective developing map (b) after adjustments*

Chopping up the skirt surface in a way so that all pieces flattened injectively was non-trivial. Foreseeing the challenges of constructing a garment with long meandering seams, we wanted to start with a relatively simple pattern that didn't have too many pieces. Ensuring that the large pieces did not overlap when flattened took multiple attempts. This illustrates one difference between creating patterns with mathematically optimal area distortion and the analog TR-method used by designers. Despite their skill and intuition, designers still encounter non-developable patterns. To fix this, they manually adjust the pattern by "easing in" or removing the area until there is no overlap. Then the pattern is redrawn and adjacent seams are edited to agree with this new piece. This process is illustrated in Figure 5.

Testing the Pattern and Next Steps

We tested the pattern using an inexpensive material, the early results were very promising. See Figure 6. We were able to confirm that the BFF program preserved lengths by checking that matching seams had the same length. However, during construction, we found it difficult to properly align the seams which resulted in an unbalanced hem and waistline as well as unsightly puckering. Therefore, moving forward we need "notch" the pattern, and also reconsider the placement of the seams relative to points of high curvature. Notching is a tool in traditional pattern-making that enforces the proper alignment of pattern pieces.

Despite the aesthetic issues with the skirt prototype, during the fit evaluation, the female subject was satisfied with the fit. The participant noted that this skirt did not gap at the waist, unlike the traditionally-drafted skirts she is accustomed to. We plan to make adjustments to the pattern, and once we are confident in the assembly and drape of the garment, make a finished version of the skirt out of fabric chosen for aesthetics.

(a) **(b)** **(c)**

Figure 6: *(a) cutout of pattern pieces (b) front view (b) side view*

This method for creating patterns has much potential for exploring questions in both mathematics and design. We end with just two such questions. Can we predict when a pattern piece will flatten injectively? Can we use an algorithmic method to create appealing patterns on our model skirt surface?

References

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