# BALLOON ENVELOPE CUT LAYOUT ALGORITHM

**Radek Kubíček**
Doctoral Degree Programme (3), FIT BUT
E-mail: ikubicek@fit.vutbr.cz

Supervised by: Pavel Zemčík
E-mail: zemcik@fit.vutbr.cz

## ABSTRACT

Computer graphics in combination with advanced numerical methods can help improvement of many products. One of the not well unexplored examples is design of hot air balloons. However, the design of the 3D shape of the balloon, while being the most important part of the design, is not the end of the design process. Preparation of the balloon fabric cut is a complex process that is critical for quality of the design while still being underestimated and approximated mostly by hand or using very simple tools. This paper addresses the issue of an automatic cut preparation based on the 3D shape and fabric features using means of computer graphics and advanced numerical methods.

## 1 INTRODUCTION

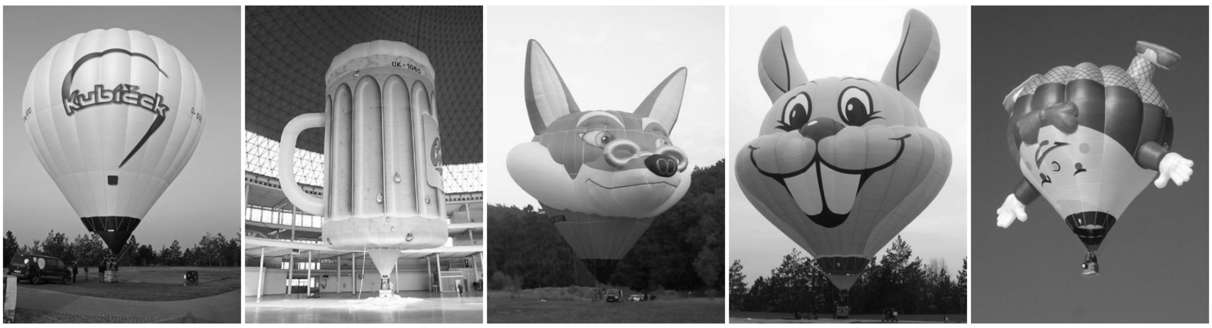


Figure 1: Examples of the various balloons envelope types

A hot air balloon has three essential parts: the burner which heats the air, the balloon envelope which holds the air, and the basket which carries the passengers. The envelope, its design, shape, and used graphics is a main distinctive attribute of all balloons with complex and difficult manufacturing and is constructed from gores made of polyamide or polyester fabric, reinforced with sewn-in load tape. The gores comprise of a number of smaller panels connected together with the seams. An envelope design determines the characteristics parameters of a hot air balloon.

## 1.1 3D BALLOON DESIGN DESCRIPTION

Good envelope shape design is necessary for the quality of the result. Hardly unfoldable panels which tend to have Gaussian curvature in more than one direction or very complicated shape need to be redesigned or divided. Unfolding of the panels to a cut design plane is often not so difficult in case of basic shape, which is shown the leftmost in Figure 1, the gores generally consist of well unfoldable panels. Nowadays, however, special balloons become popular, which could have very complex shape, as you can see in Figure 1. Unwrapping of the separated panels is a very complex process with many parameters. Probably, it is the main reason that it is still done by hand or only using simple tools well usable only for basic or not very complex shapes which causes whole development to be time and money consuming.

# 2 HOT AIR BALLOON SHAPE AND DESIGN

Consider a 3D balloon model divided into mutually connected panels having in most cases quadrangular or triangular shape. Every panel is affected by the inner hot air stress force and the forces caused by the adjacent panels. These forces cause a stretch whose extent depends on fabric physical parameters.

## 2.1 PHYSICS OF THE FABRIC

The main physical parameter of the fabric is elasticity. It could be described through a stress-strain curve which determines the force applied on panels. Elasticity varies according to the angle of force application. The desired layout feature is such that the main axes of the panel are collinear with the fabric texture but this could not be reached for all shapes. The seam itself is special case – because of multiple fold and sewing it could be considered as solid and fabric physical properties do not take effect. Figure 2 shows the curve of elasticity of the used fabric in two main directions. A weft and warp orientation depends on the type of the balloon. Warp stays for a horizontal and weft for a vertical direction of fabric texture in the most cases, but it could be different sometimes [1].

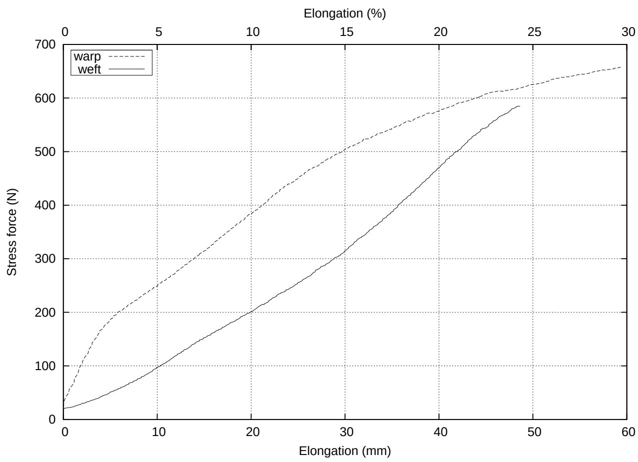


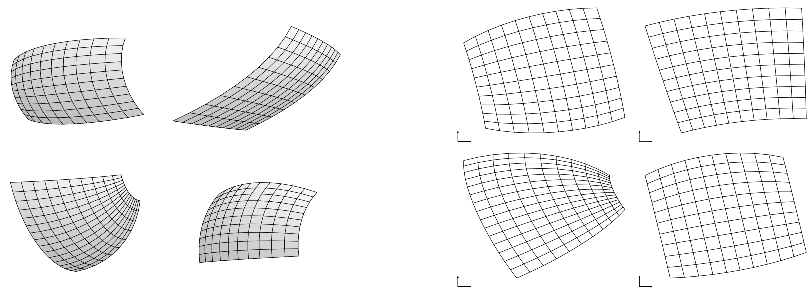

Figure 2: Stress-strain curve of the fabric used for balloon construction.

### 2.2 DESIRED PROPERTIES

During the unwrapping process, all physical parameters should be preserved, especially panels' edge lengths. Because the size of a panel could be from few centimeters to several meters, it is necessary to specify an error metric. Acceptable deviation is about 1 millimeter in 1 meter, which means a maximum acceptable error of 0.1 %. However, the sewing process accuracy is about 1 millimeter, so it is not needed to achieve any better accuracy. Also, it is important to fit two adjacent panels which means to reach the same or very similar length of their common edge.

## 3 AUTOMATIC CUT DESIGN ALGORITHM

Panels need to be approximated by a grid of the quads before the unwrapping using uniform tessellation. User defined or automatic tessellation respecting the maximum allowed error of a panel shape approximation is applied. During a tessellation process, necessary parameters are calculated and saved into the grid elements; 3D coordinates for points, length for line segments, area for quad basils, and length for every edge. Before the unwrapping process starts, given coordinates are transformed onto projection plane using the PCA method.



(a) (b)

Figure 3: Panel tessellation examples in (a) 3D model space (b) a projected 2D cut design plane.

### 3.1 MATHEMATICS DESCRIPTION OF THE PANEL

Each point contains its 2D coordinates and its grid position, each line segment contains required and actual length and for each basil is saved its circumference and area, the whole grid contains the total area and circumference, and for each edge is saved its required and actual length. During each step in the simulation, the values stored in each element are updated according to the force applied to them. We use standard Newtonian equations of motion to convert a force to point motion and Euler's method to advance the current velocity and position over the each time step. To simulate a fabric behaviour, we calculate forces in points through basils instead of themselves. In contrast to ordinary particle system, that is necessary for preserving fabric physical properties. In the Equation 1, we replace the direction by **D** with possible values **V** and **H** which stay for vertical and horizontal edge connected to the point $i$. For each point $i$ we calculate force respecting basil deformation using the equation

$$\vec{F}_i = \vec{F}_{\mathbf{H}_i} + \vec{F}_{\mathbf{V}_i} \quad \text{where} \quad \vec{F}_{\mathbf{D}_i} = H \cdot \frac{S}{4} \cdot \frac{\Delta \mathbf{D}_i}{l_{\mathbf{D}_i} \cdot k} \cdot \vec{\mathbf{D}}_i \quad \text{and} \quad S = \begin{cases} l_a + l_b & \text{if } \mathbf{D} \text{ is } \mathbf{V} \\ l_c + l_d & \text{if } \mathbf{D} \text{ is } \mathbf{H} \end{cases} \tag{1}$$

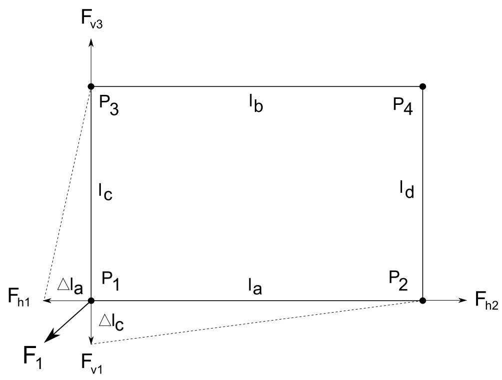



Figure 4: Point force calculation through basil.

where $H$ denotes a hardness of the edge which is biggest on the seam, and $k$ stays for an inverse force value of percentual edge length error $\Delta\mathbf{D}_i$ calculated using the stress-strain curve selected in accordance with a fabric orientation in the panel. $l_{\mathbf{H}_i}$ and $l_{\mathbf{V}_i}$ are length of edges. Sign of the edge error in combination with the vector $\vec{\mathbf{H}}_i$ or $\vec{\mathbf{V}}_i$, which denotes vector along the particular edge starting in the point $i$, determine direction of the force action.

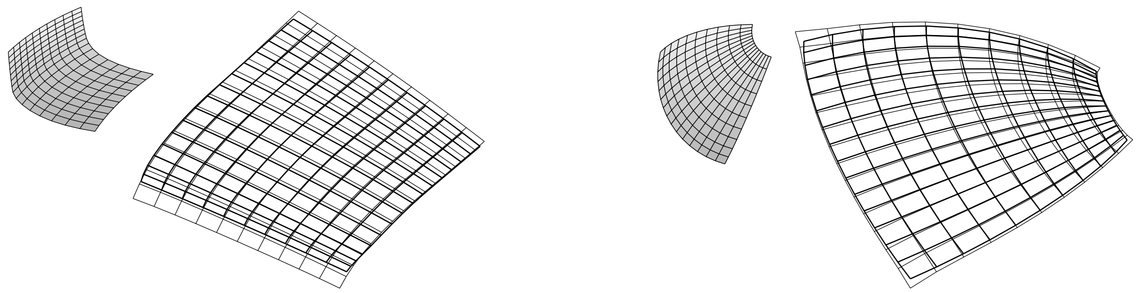
An important part of the force calculation process is also how to deal with diagonal oriented deformation of the basil. The mathematical background of the fabric deformations is very complex and difficult and it is not necessary to handle it perfectly. For this purpose, it is enough to approximate fabric deformation physical properties with a simple approach. We calculate an original diagonal ratio as $r_d = l_{d_1}/l_{d_2}$ and in each step of iteration, new diagonal ratio is calculated and compared to the original. If a new ratio is greater than 1, the basil is stretched along a diagonal $d_1$, otherwise along a diagonal $d_2$. Because we want to preserve shape of the basil as well as possible, we apply a small shortening force along the main stretch diagonal and elongation force along the other diagonal thus we try to balance the ratio of diagonal lengths.

For endlessly behaviour of an algorithm, we need to define the end conditions for an unwrapping process. Automatically, an end condition puts up when all edges reach length we demand and an area error is acceptable. This condition could not realistically be applied for all panels and it is necessary to define the other end condition. For example, it could be specified as a long-term stabilization of a whole system forces summation or a long-term unimproved solution accuracy.

## 4 EXPERIMENTS

The experiments with the proposed approach currently include only numerical solution of the unwrapped panels and their comparison with the traditionally prepared ones. The purpose of the experiments at this moment is expert judgement of the feasibility which will be followed by design and building of the balloon model. During the numerical solutions, the error along the panel is evaluated.

Figure 5 and Table 1 show results of some performed experiments. We can see that basic shapes are unwrapped well with small error (Fig. 5(a)), since the error of more curved shapes unwrapping is bigger and sometimes much bigger than the acceptable value (Fig. 5(b)) and the unwrapping process also takes more time. Bold values in the table are problematic.



(a) (b)

Figure 5: Examples of panel unwrapping results. 3D shape of the panel and comparison of the 2D shape before unwrapping starts (thick line) and after it ends (thin line).

| | Edge 1 ($mm$) | Edge 2 ($mm$) | Edge 3 ($mm$) | Edge 4 ($mm$) | Area ($mm^2$) |
|---|---|---|---|---|---|
| a | −1.601 / 981.176 | −0.458 / 805.465 | 0.289 / 869.067 | 1.479 / 878.015 | −11273 / 775950 |
| b | −1.00 / 1380.08 | **8.40** / 1534.33 | 0.16 / 455.23 | −**3.22** / 1567.60 | −109419 / 1669645 |

Table 1: Statistical evaluation of the results error (value difference / wanted value).

## 5 CONCLUSION

The presented work aims at automatic unwrapping algorithm of a hot air balloons envelope, a whole process simplification and creating the system which is capable to solve this problem. We defined success metric which results of unwrapping process needs to accomplish and we implement a differential equations system useful for solving unwrapping problem, such as a combination of a particle system and advanced numerical methods. The results obtained through the automated process are promising. They are different than the ones obtained “by hand”, most probably they are better and in any case, they are much faster and easier to obtain. However, the evaluation through building a real balloon based on the results yet has to be done. Future work includes reflecting mutual topology of balloon panels, their common edges lengths, and improvements and stabilization of the unwrapping algorithm.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