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DEVELOPING UNDEVELOPABLE SURFACES USING PARTICLE SYSTEMS

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Abstract: This paper presents a new approach for calculating a development of an undevelopable surface using a particle system. An undevelopable surface is any surface that cannot be flattened into a map without stretching, tearing, or compressing itself, as for example the surface of a sphere. While geometry based algorithms for solving this problem usually introduce large distortions to the development, the technique presented here allows calculating a development with minimal distortion.
The technique was developed to enable automatic calculation of 3d-models of made to measure shoes based solely on the CAD-/CAM-data used for construction and production. It is embedded into a web-based process-chain which aims at reducing the costs for manufacturing custom-sized shoes, and thus supporting traditional shoe-makers.

Keywords: Computer-aided design, Computer-aided manufacturing, Computational Geometry, Process-automation

1. INTRODUCTION

The most important tool of a shoemaker is the last. This is an abstract copy of the human foot which reflects the individual measures and proportions of the latter. The last builds the basis for both the construction and the manufacturing of a shoe. For construction of the required shaft parts for a shoe, a shoemaker creates a two-dimensional development of the surface of the last called the last-flattening. By application of an approved procedure, the correct transfer of the proportions from the last into this template is assured.
The last-flattening builds the basis for shaft construction. The contours of the leather parts required for manufacturing the shoe are derived from this template, which guarantees that the measures and proportions contained in the flattening are carried over correctly into the shaft parts. This procedure ensures the fitting accuracy of the shoes, since the individual measures of the foot flow from the last into the last-flattening, from there into the shaft construction and finally into the shoe (Sahm, 1978; Vass and Molnár, 1999).
The proposed method for visualization of made to measure shoes makes explicit use of these circumstances. It is based on the following idea: Since the shaft parts of a shoe are derived from the last-flattening, it is possible to describe their positions in a geometric relation to the flattening. Since the flattening corresponds to a development of the surface of the last, the exact position of the shaft parts on the last is distinctly determined as well. To finally transfer the shaft parts onto the last, and thus calculate a model of the shoe, a projection-function is required, which allows to locate the position of arbitrary points from the flattening on the last.
Once all contours of the shaft parts have been transferred to the last, it is possible to calculate a wire frame model of the shoe with common techniques from computational geometry (de Berg, *et al.*, 2000). This is possible because both, the basic shape and all

characteristic qualities of the shoe are clearly determined by the CAD-data available.

2. CAD ASSISTANCE IN SHOE-CONSTRUCTION

In earlier research projects a model for the computer-assisted construction of made to measure shoes has been developed (Plath, 2004). Meanwhile the results have been implemented in a comprehensive internet-based communication and production platform. The platform allows traditional shoe-makers to present their products and customers to order made to measure shoes. The complete process from the production of the last to the delivery of the customized shoe is supported by the platform. Hence the price of a pair of shoes can be reduced by ~40%. The visualization approach described in this article extends this platform with the possibility to give potential customers a preview of their desired shoe, with respect to individual attributes such as the chosen type of leather or custom decorations.
The platform supported process-chain covers the following three phases:

- *Production of a virtual last based on customer data*
- *Construction of a virtual last-flattening after measurement of the virtual last*
- *Construction of shaft parts by model variation of the flattening*

For shaping the virtual last, a CAM tool is used, which permits a shoemaker to create an individual last by first selecting a roughly suitable raw last from a library which can then be processed with different tools until it corresponds to the exact dimensions of the foot of an individual customer. The geometry of that virtual last is then transformed into a wire frame model.
The construction of the accompanying last-flattening is carried out in two steps: First, the virtual last is measured. To do this, 25 prominent points are defined on its surface and measuring sections are created between these points. Afterwards, a shortest-path algorithm for surfaces is applied to calculate the distances between these points (Figure 1).

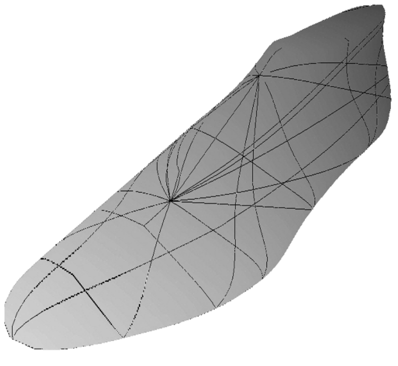

Fig. 1. A virtual last with highlighted measuring sections

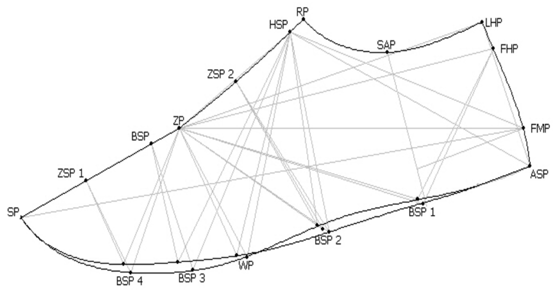

Fig. 2. The corresponding last-flattening

The acquired measures are used to construct the contour of the last-flattening using a sequential constraint solver (Sunde, 1988; Anderl and Mendgen, 1996). For this – as well as for the construction of the shaft parts – the pattern construction system COAT developed at the University of Bremen is used (Szczepanek, 2003; Rödiger, 2000). The CAD system COAT is also used for construction of the shaft parts. The constructed last-flattening is used as a basic pattern on which the construction of an individual shoe model builds up. This ensures that the designed shaft parts actually match the accompanying last, since all measures and proportions are given by the last-flattening. Figure 3 shows an exemplary construction. It also clarifies the relation between shaft parts and the last-flattening.
Since the knowledge of the geometric relation between a shaft part and the last copy is the key to determine its position on the virtual last, it is additionally necessary to add reference points from the last-flattening to every shaft part during the process of construction, as shown in Figure 4. These points make it possible to reconstruct the relative position of a shaft part by a simple affine transformation and therefore permit to transfer it onto the virtual last later on.

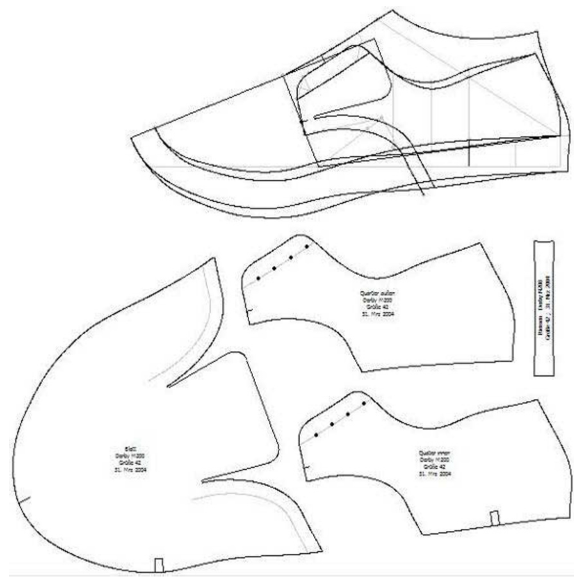

Fig. 3. CAD construction of a Derby model. The individual parts of the shoe are derived from the flattening