

DEVELOPMENT OF A LOW COST FOOT-SCANNER FOR A CUSTOM SHOE TAILORING SYSTEM

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INTRODUCTION

We propose a low-cost foot scanner to replace the expensive ones. Components used in our scanner and shape acquisition method are entirely different from those of other classical foot scanners. Several PC cameras are used instead of expensive CCD cameras. Also, the suggested scanner does not require expensive moving mechanism, emitters (laser generator or pattern generator) and some controllers. In shape acquisition process, the foot database concept is newly introduced. And we used stereovision technique and several deformation techniques to reconstruct a foot model. The scanner is made in a form that is simple enough to barely verify the proposed reconstruction method (Fig.1). For the verification, several strangely shaped foot models were fabricated and reconstructed using the suggested low-cost foot-scanner. Although the proposed scanner is not as accurate compared to the high-end active optical scanners, but it has been confirmed to be sufficient to be applied in custom-tailoring shoes.

REVIEW AND THEORY

There have been many efforts to reduce the cost of commercial foot scanner. Blais designed 3 special optical sensors to reduce the cost of foot scanner (Blais et al., 2000). M.Kouchi applied the concept of "homologous shape modeling" (M.Kouchi et al., 2001) and Leon Kos introduced "automatic detection of anatomical landmarks" (Leon Kos et al., 2002) to design the low cost foot scanner which not only extract the foot shape but also suggest the customized shoe last. But the costs of these scanners are still high to be used in conventional retail shops, because these foot scanners still adopt classical shape acquisition methods, i.e., active optical scanning methods that need expensive components.

In our approach, we do not directly calculate the coordinates of points on the foot except several points that determine major foot parameters (foot length, ball width, instep height). Foot shape is reconstructed based on the contour of captured images. In this sense, our 3D shape acquisition method is not a scanning but a reconstruction from 2D images. Actually, we get the final foot shape by deforming the sample foot data. (Sample foot data can be one of foot data in database or the result of morphing process)

PROCEDURES

Overall process consists of 3 steps, that is, pre-process, measuring process and reconstruction process. (Fig.2) Firstly, various types of foot shapes should be created and stored in a foot database. Each foot data is represented in a simple and homologous form. Also camera calibration process is needed to derive the camera position and orientation relative to the origin. We use Tsai's traditional calibration method. Pre-process is done before we measure the customers' foot.

In measuring process, we get 12 images taken from 12 cameras at different positions and angles. By applying several image processing skills, foot area is extracted from each captured image. With the help of stereovision technique, we can easily calculate major foot parameters, that is, foot length, ball width and instep height. And all DB foot data are scaled so as to have the same length with the measured foot. (From now on, we simply call the foot data in database DB foot)

Reconstruction process is composed of 3 sub-steps. First of all, we perform similarity analysis between the measured foot and DB foot. Similarity analysis is the process of comparing the captured PC-cam images with projected images of DB foot. Projected images are generated using virtual cameras. Each virtual camera is positioned in the same position and orientation as the corresponding real camera. So, with virtual cameras, we can obtain 12 projected images of DB foot and calculate the difference between measured foot and DB foot. As a result of similarity analysis, DB foot data are graded from the first rank to the last rank. In here the first rank means the most similar foot in the database to the foot being measured. Grading process is followed by morphing process. In brief, morphing is an iterative process, which compares various morphable models with measured foot and selects the best matching model. Morphable models can be easily generated as a linear combination of the shapes of m exemplar foot data in the database (Volker et al., 1999). With morphing process, we create a new foot shape that does not exist in the foot database and can get more similar foot to the measured foot than the 1'st ranked DB foot. Reconstruction process is completed with a local deformation process, that is, refinement process. By extending t-FFD (Free-Form Deformation by using Triangular Mesh) algorithm (Kazuya et al., 2003), we created local deformation algorithm. And by applying this local deformation algorithm, we deform the shape locally and can get refined final foot shape.

RESULTS AND DISCUSSION

To verify the suggested foot scanner, we tested 10 strangely shaped foot models as explained below.

1. Make a plaster foot model.
2. Get 3D foot data of plaster model using high-end scanner (measurement error is less than 0.1mm).
3. Reconstruct 3D foot data of plaster model using the proposed scanner.
4. Error between two data is calculated using 3D distance field. Distance field means a space where every point of one shape has a corresponding value indicating its Euclidean distance to the nearest points of the other shape.

It can be noticed that the average error is less than $\pm 1.5mm$ after refinement process. According to the footwear experts, $\pm 3mm$ error in average is allowed for custom shoe tailoring. Among 10 test models, 2 cases are represented in Fig.3. Average error and value of maximum error point are represented. Also when we consider shoe making, error estimation using major foot parameters (ball width, ball girth, instep height, instep girth, etc.) is more significant than the one using 3D distance field. Each parameter difference between two data is less than $\pm 2mm$ and this error is also permitted in custom shoe tailoring.

Even though the accuracy is not as good as high-end foot-scanners, it's enough to be used in custom-tailoring shoes. As the most important thing, our foot-scanner is superior to any other foot-scanners in economic aspects. The price is greatly cheaper than that of commonly used scanners and this allows the use of the system in conventional retail stores.

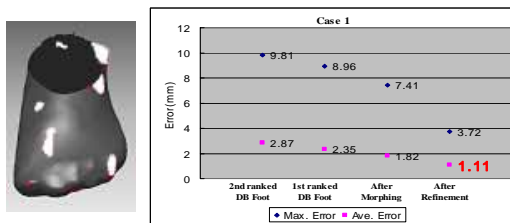
There are a few open issues concerning the method presented in this article. For accurate and efficient reconstruction, more foot data should be stored in database. Therefore we try to update foot database regularly. Also we are working on developing the efficient reconstruction method from 2D images.

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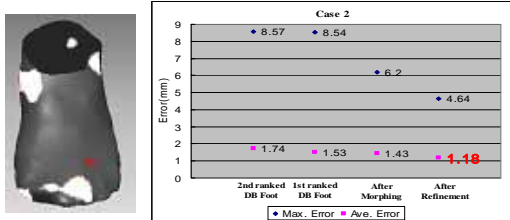
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Fig. 1. Configuration of suggested low cost foot scanner



CASE 1: Short Size, Big Ball and High Instep



CASE 2: Middle Size, Small Ball and Low Instep

Fig.3. Two case studies (Black area: Area where errors are less than $\pm 3mm$)

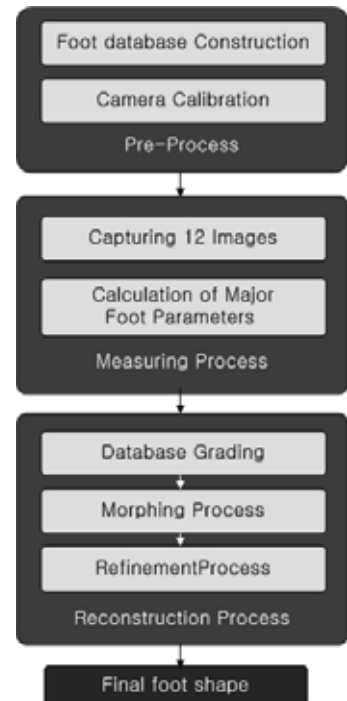


Fig. 2. Overall Process of scanning system