Shape Completion and Modeling of 3D Foot Shape While Walking

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Abstract—We developed a technology for creating homologous models of foot shape data obtained from a 4D measurement system. Homologous models consist of the same number of the same topology, and each data point in the model is defined based on the anatomical homology.

In the present modeling technology, we use a homologous model using a polyhedral template. By fitting the homologous foot model to data obtained from 4D measurement system, our approach can accomplish homologous modeling for 4D-measured data. We show how the model can be used for shape completion and modeling —generating a complete surface mesh and granting anatomical feature points given a limited set of captured points specifying the target shape.

Using principal component analysis (PCA) and posture change, we accomplish homologous modeling for 4D-measured data of human foot shape.

Index Terms—anthropometry; homologous model; deformable model; principal component analysis; 3D model fitting

I. INTRODUCTION

In recent years, anatomy and biomechanics have been widely used in criminological and medical applications, and in usability testing of products. They also play an important part in ergonomic design [1]. For such purposes, accurate measurement and modeling of human shape is necessary. Nowadays, 3D full body scanners are available. For example, shoes should be designed in consideration of a user’s foot [2]. Ideally, design of shoes should consider not only static shape of the human body, but also dynamic shape while walking, running, and so on.

The Digital Human Research Center (DHRC) developed a measurement system of anatomical feature cross-sections using multiple view stereo matching, which can measure foot shape while a subject is walking [3]. In this way, they aim at accurately measuring dynamic shape of the human foot in motion (i.e. walking or running). But the system can measure only feature cross sections. Therefore, the measurement of the whole 3D foot shape should be accomplished as the next step. Accordingly they have developed a 4D measurement system [4](consisting of 4 camera-projector units) that can measure the foot shape at 200Hz[Fig.1].

The 4D measurement system comprised one video camera and one projector. A single pattern was projected onto the foot surface, and the reflected pattern was captured by the video camera. The pattern was formed using small color cells of 2 × 2 pixels. Nine types of 2 × 2 RGB color distribution were pre-defined, and each cell randomly showed one of the 9 color codes. The 2D positions of each cell were also random. Such randomness helped a standard stereo-vision technique, which identified the 3D location of cells. Calculating for all available cells in video images, the surface shape was obtained, and the 3D shape could be calculated from a single video frame. This system captures approximately 100 frames of the shape data for one step of walking, and about 50 frames for one step of running. However, measured data have several problems.
First, measured data have many deficit parts and holes due to occlusions and the light patterns are not projected on the measured objects.

Second, the measured data do not have anatomical information, only have coordinate information (xyz) as point-clouds. Therefore we cannot quantitatively use 4D data about foot deformations while the subject is walking.

Third, there is no widely accepted methodology for analyzing a time-series of body shape data.

To make effective use of measured data, we have to complement deficit parts and add anatomical information to the measured data. In other words, we need to perform shape completion and modeling of time-series foot deformation data.

II. METHODS

We want homologous model to deform for fitting to each frame of 4D-measured data. Active Shape Models (ASM) [5] and Skinning algorithm [6] is applied for foot model to realize shape deformation and postural change.

A. Acquiring and Processing homologous model

Homologous model consists of the same number of the same topology, and each data point in the model is defined based on the anatomical homology. We use homologous foot data that was generated by extracting 1946 points from full-body 3D homologous models Dhaiba (Digital Human Aided Basic Assessment system) [7]. In this way, we prepare 52 homologous foot data and normalize scale of the foot models. In addition, we set articulated joint structure on homologous model, which is used in skinning method. With Magnetic Resonance Imaging (MRI) data of some feet, we obtain estimated regression equation that infers three dimensional coordinate between anatomical feature points and internal joints in human foot. As a result we generate some joints on homologous model by applying the multiple regression.

B. Active Shape Models

We analyze these foot models by the statistical method. The purpose of using PCA for foot models is to move points of homologous models with human body constraint. After applying PCA, each point in the subspace basis on some principal components means a model which has particular foot shape. Therefore, we can obtain a foot model which has an arbitrary foot shape by back-projecting a point to the original sample space (1946 x 3 = 5838 dimensions). Hence we are able to deform model shape with parametric and constrained.

C. Postural Change and Shape Deformation

In order to realize shape deformation resulting from postural change, we implant hierarchical bones which consist of articulated joints structure in a foot model. Besides, we implement a surface skin deformation algorithm called Skinning. The geometry of the surface skin is deformed along with the change of the joint angles.

D. Model Fitting

The goal of the model fitting step is to determine the values of all of parameters that best fit the each measured data.

We define cost function on the basis of Euclidean distance between each point of the model and nearest point in each frame of 4D measured data. First of all, for one of the 4D measured data in stance phase of gait, we manually align with homologous model at the heel position of the measured data and adjusting scale of the foot model. After first alignment and length adjustment, we perform shape deformation by changing PC scores (PC optimization).

Second, in order to fit other measured data, we perform skinning algorithm (Pose optimization). We optimize each variable which measures three dimensional rotations by using Levenberg-Marquardt algorithm.

III. RESULT

Figure 3 and Figure 4 shows the result of the homologous model fitting to some of 4D measured data. The average distance between each model point and the nearest point of measured data is about 4.0 mm in the case of initial data. The error is increased by being away from stance phase of 4D measured data.
IV. Conclusion

In this paper we proposed a model-based method of fitting a template model to 4D-measured data, which is captured by multiple pairs of camera and projector while walking or running. Using a homologous foot model as a template, the significant problems of measured data (there are a lot of deficit parts and there is no anatomical information in measured data) were solved efficiently. For the purpose of fitting a template model to measured data, we used PCA and Skinning algorithm. However, there is no reference data on dynamic foot shape deformation in motion, it is very difficult to validate deformation method correctly. Furthermore, we have to consider certain non-rigid deformation in motion which is often occurred due to the contact on the flour and external force on the foot. For our future works, it is needed to implement non-rigid deformation method and fitting homologous model to 4D measured data as close as possible.

References