

Parametric-based reconstruction of 3D mesh models; towards the generation of a parametric human foot biomodel

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Abstract

In this work a new reconstruction technique is presented based on Parametric-Based Deformation. The new method uses a template 3D mesh model which is deformed according to user-defined semantic parameters in order to derive a new 3D object. The proposed methodology is divided in three stages: template construction (production of a template mesh model), regression (the template model is deformed to match sample models) and prediction (new instance mesh models are derived based on user parameters). The proposed method has been successfully applied for the reconstruction of human and animal skeletal models. A practical and novel reconstruction methodology has been developed and implemented for the reconstruction of the human foot given a bi-planar X-ray. The purpose of this methodology is to support the parametric generation of human foot biomodels in an automated way. The generated biomodels are employed by simulation tools based on Finite Element Analysis to test the stress factors that the foot is undertaking during its contact with the ground or a footwear sole structure.

1. The basic parameterization methodology

The automatic generation of a 3D model which belongs in a specific category like a human body, face or bone, with specific semantic parameters is an important topic in CAD/Computer Graphics. There is a plethora of applications involved in this process, like for example crowd simulation, animation and garment design based on specific body-type and height. Concerning bones, this process is crucial because it reduces the time a bone is reconstructed which is vital for in-vivo situations like quick diagnosis from the doctor and fast/accurate surgery preparation. Also by this way the patient is not exposed to hazardous CT scan radiation, while the need for undergoing the tedious process of MRI scan is minimized. Parametric bone reconstruction is also important in applications which employ bio mechanical analysis with the use of Finite Element Method (FEM).

This work describes and illustrates the last application mentioned above. The methodology used follows the concept introduced in [LJ14] where a given prototype 3D mesh \mathbf{P} is deformed to a new 3D mesh \mathbf{M} according to given parameters $(p_1^M, p_2^M, \dots, p_k^M)$. The whole procedure is based on three stages, illustrated also in Figure 1. First mesh simplification which preserves topology is applied to \mathbf{P} acquiring mesh \mathbf{P}_c which is called as *control mesh*. In the first stage, a mapping between the prototype mesh \mathbf{P} with

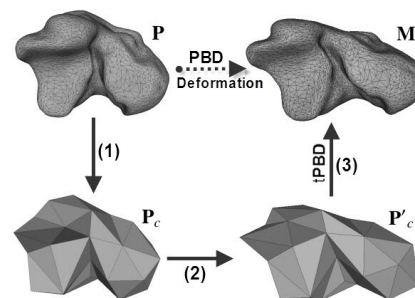


Figure 1: The basic stages of the proposed methodology: (1) Generation of \mathbf{P}_c and establishment of relationship between \mathbf{P} and \mathbf{P}_c . (2) Modification of the control mesh \mathbf{P}_c to \mathbf{P}'_c using the input parameters. (3) Generation of the new deformed shape \mathbf{M}

the control mesh \mathbf{P}_c is established. At the second stage, the control mesh \mathbf{P}_c is modified using a linear transformation with parameters $(p_1^M, p_2^M, \dots, p_k^M)$ deriving the control mesh \mathbf{P}'_c . At the third stage, the modified control mesh \mathbf{P}'_c is used to deform mesh \mathbf{P} into \mathbf{M} .

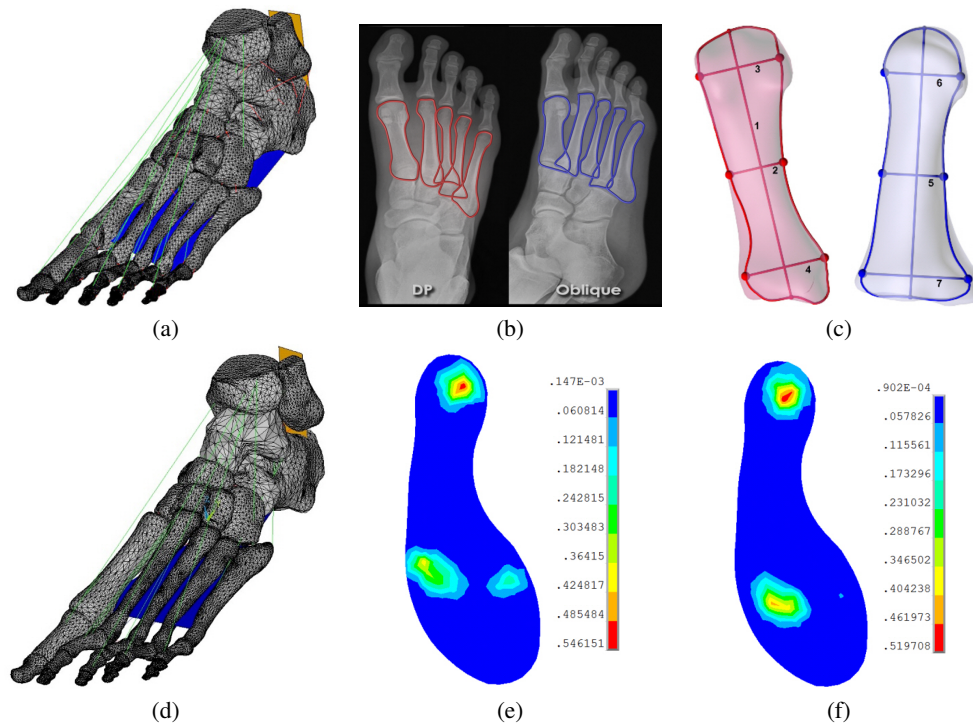


Figure 2: (a) Original biomodel. (b) Contours of the metatarsal bones. (c) Measurements (parameters) used. (d) Custom biomodel conforming to the X-ray. (e) Plantar pressure distribution of the original biomodel. (f) Plantar pressure distribution of the new biomodel.

2. Experimental test case : Biomodel production

The proposed parametric-based deformation method has been successfully applied for the production of foot biomodels for mechanical simulation analysis by using custom bone measurements taken from bi-planar foot X-rays. Modern approaches in footwear design employ simulation tools based on Finite Element Analysis (FEA) to test the stress factors that the foot is undertaking during its contact with the ground or the footwear sole structure, in order to construct comfort or orthopedic footwear [PKA14].

A detailed biomodel has been developed using a combination of CT scans and a reverse engineering surface reconstruction approach consisting of 26 bone meshes, 33 joints and various tendons as it is shown in Figure 2(a). Using the proposed methodology all bone models are represented by parametric template models which are able to deform according to given measurements. For example, given a bi-planar X-ray like in Figure 2(b), all metatarsal bones are parameterized using seven measurements/parameters which are computed on the corresponding bone contours utilizing both DP and Oblique views (see Figure 2(c)).

We were able to reproduce all the metatarsal bones and derive a custom biomodel of the foot depicted in the given bi-planar X-ray. The new biomodel is illustrated in Fig-

ure 2(d). Finally, Figure 2(e)&(f) present and compare the analysis results derived by using the two aforementioned biomodels. The results depict the maximum plantar pressure of the human foot standing on a floor (mid-stance Gait phase) with a 50 kg load. The results related to the derived biomodel comply with the loading parameters and the changes in the model geometry.

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