

Contour-based Repositioning of lower limbs of the GHBMC Human Body FE Model

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I. INTRODUCTION

Advanced Human Body Models (HBM) are increasingly being used for injury prediction in passive safety analysis. However, HBMs are often underutilised because they are typically available only in a few limited postures and therefore fail to represent the variability of postures in the crash environment.

Efforts have been made to generate posture-specific HBMs derived from the typical occupant posture HBMs [1-3], however the described methods are computationally expensive and generally require a significant amount of time (in the order of hours) to position the HBM into a new posture. Jolivet *et al.* [4] describe a sofa-based positioning technique implemented within the PIPER platform. This technique uses a lightweight physics-based method for repositioning.

Jani *et al.* used a set of predefined contours to reposition the knee and hip joints [5-6]. The work presented in this paper describes a generic approach for repositioning the HBMs, which improves on the method used by Jani *et al.* by automatically generating non-intersecting contours based on a predefined curve passing through the centre of all body regions. This paper presents the results of the technique as applied to the lower limb joints of the HBM. This study forms part of one of the methods implemented as a module within the PIPER framework [4] [7] to reposition the HBM. Additionally, the PIPER (Position and Personalize Advanced Human Body Models for Injury Prediction) framework includes display/visualisation, input/output, as well as other modules, such as smoothing, that can be applied subsequently. The method described in this paper will be available under the Open Source GPL v2 license within the PIPER framework.

II. METHODS

The contour-based deformation technique used in this paper can be summarised as follows.

Contour-based Positioning Module

Contours are defined as closed, non-intersecting curves, like polylines, ellipses or circles, enveloping the HBM. The first step when repositioning the HBM involves the creation of a curve passing through the important landmarks on the skeleton; this curve is referred to as the contour control line (contourCL). Contours are created near the intersections of the surface of the body region and planes perpendicular to this contourCL curve. The next step requires the generation of the Delaunay tetrahedrons using the contours and the nodes of the bone of the corresponding body part; these tetrahedrons are used to map the model mesh nodes using volume coordinates. The final step consists of the transformation of the contours as per the desired input, and it is expected that the key points (for instance, the bone nodes) are also transformed using the same parameters. At the end of the third step the final positions for all contour points, as well as all the key points, are available. These are used to remap the mesh nodes to their new positions.

Repositioning of Lower Limb Joints

For the lower limbs of the HBM, the contourCL passes through the proximal and distal landmarks of femur and tibia bone. ContourCL is linear at the thighs and the ankle-to-calf regions and is a spline at the knee joints. Contours for the thigh body regions, knee joints, ankle-to-calf body regions, ankle joints and foot body regions, which are all perpendicular to this contourCL. When considering the repositioning at the knee joint, the contours at thigh region remain fixed, while contours at the knee, ankle-to-calf region, ankle and foot are modified by affine transformation. In the knee region a spline is defined that forms the skeletal definition of the knee. Each contour on the knee joint is positioned along the length of this spline, which governs the transformation of the knee joint. The contours at the knee joint are transformed with respect to axis defined by landmarks on the femur, ensuring the anatomical correctness of the positioning. The contours of the rest of the limb go through the same affine transformation as that of last knee contour.

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This type of transformation ensures that there is no intersection among the contours. The same process is employed when considering the repositioning at the ankle. The technique uses various landmarks on the human body, defines joint positions and axes based on the same, generates splines based on these landmarks, uses the spline to generate contours, and then applies the techniques described in this paper.

III. INITIAL FINDINGS

Figure 1 is an example of the final results delivered by the contour-based repositioning technique. It shows the initial model (with the skeletal contourCL), the generated contours, contours repositioned for movement at the knee, and the final repositioned knee. The process takes about 4.5 minutes on a machine with 16GB RAM, Intel Xeon E5-1620 CPU, NVIDIA GTX 780 GPU, running Windows 7.

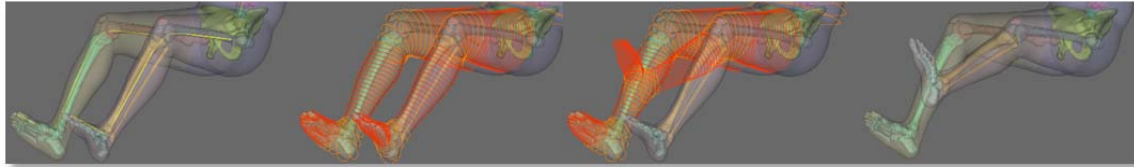


Fig. 1. The process of knee repositioning by 30° for the GHMBC model.

Table I shows the number of elements below Jacobian cutoffs of 0.6 and 0.95 before and after repositioning. The number of elements violating the minimum Jacobian of 0.6 is almost constant. It also shows that the minimum Jacobian remains at 0.151. Figure 2 shows the initial model and the model after inversion of the right ankle joint by 30° and extension of the left hip joint by 30°.

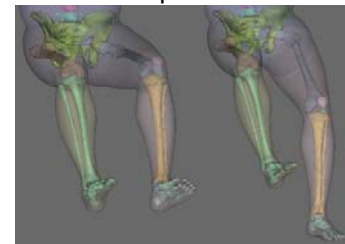
TABLE I

COMPARISON OF JACOBIAN VALUES FOR HBM BEFORE AND AFTER KNEE FLEXION

Jacobian Cutoff	Number (%) (min. value) of elements violating	
	Original	After Flexion
0.6	8186 (1.59) (0.151)	8195 (1.59) (0.151)
0.95	295670 (57.4) (0.151)	295647 (57.4) (0.151)

Fig. 2.

Model after repositioning at the hip and ankle.



IV. DISCUSSION

The HBM repositioning technique presented here can serve as a viable method for generating posture-specific HBMs. This technique is implemented and tested for the following joints: ankle joint under inversion/eversion; plantarflexion/dorsiflexion and axial rotation; the knee joint under flexion/extension; the hip joint under flexion/extension; abduction/adduction; and under internal/external rotation. Delaunay triangulation is used as a method of partitioning a 3D space into small tetrahedrons. The major advantage of this technique is computational efficiency; reducing the time required to position the HBM to a few minutes, while at the same time ensuring that the repositioned model has an acceptable mesh quality.

V. ACKNOWLEDGEMENT

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