Contour Based Personalisation of Human Body F.E. Models

Abstract

This thesis presents methods to make personalized Finite Element Human Body Models (FE-HBMs) from existing anthropometry and posture and re-position models with the goal of increasing the fidelity of vehicle crash simulations. Vehicle safety research has been based on the shape and size of the "average" human body, which does not reflect the diversity of human proportions. The availability of an anthropometrically consistent model of the human body's is needed to accurately predict how an individual will react when struck in simulated crashes, the rest being taken care of by mechanics running on large silicon infrastructure. However, generating these HBMs ab initio from medical scan data is computationally and resource-intensive, requires significant human intervention, and, in some cases, the need for testing on post-mortem human subjects. Towards alleviating these challenges, this work introduces a fully automated workflow for rapidly generating HBMs that represent an individual’s anthropometry. The workflow uses a nominal HBM as a baseline, adapts it to the target individual's anthropometric data, repositions it to specifications and outputs a personalized HBM.

This workflow consists of three interconnected modules: the first is the detection of landmarks and body-part segmentation from an individual's 3D point cloud scan using computer vision. A total of 38 anthropometric parameters (length and circumference measurements) and joint angles are tracked in this work. The second module, the primary contribution of this research, “morphs” a nominal baseline HBM to the target anthropometry of a specific individual without operator intervention, thereby enhancing mesh quality and reducing computational overhead compared to earlier attempts.

Contour Control Line(s) (or ContourCL), which are often length-aligned in skeletal bones, are defined as joins of predefined anatomical landmarks along the skeleton of a human body model, thereby generating an anatomical class for the HBM personalization process. These contour control lines are encoded as a tree data structure, in which each node represents a contour control line element (or a ContourCL element). The tree root node is identified with the center of the sacrum. This root node has the left hip, right hip, and the lumbar joint as its child joint nodes. The lumbar joint extends the tree upwards, with parent-child relationships among the vertebrae, shoulders, and head, and the hands as the leaf nodes. Similarly, the hip joints subtree extends downwards, containing thighs, knees, calves, ankles, ending at the feet as the leaf nodes. By traversing the tree, a series of polygonal curves, or contours, locally orthogonal to the ContourCL is generated, which for the baseline HBM, completely encloses the soft tissues. The set of points describing these contours for each anatomical segment is coded using Delaunay tetrahedralization. Since the contours completely envelop the HBM, all the FE-nodes lie inside the convex hull of the set of contour points, and hence, every node lies inside at most one of the generated tetrahedra. Each node of the finite element model is then mapped to tetrahedral coordinates. The tetrahedra get transformed as the contours are transformed to match the target anthropometry. The Cartesian coordinates of the modified FEM node are computed from the tetrahedral coordinates of the FEM nodes and the Cartesian coordinates of the contour points of the inscribing tetrahedra.

The third module uses the ContourCL contours to re-position the model into the correct position to achieve the desired posture. Rotating and aligning the contours to the desired pose, and then applying inverse

Delaunay mapping transforms the HBM while maintaining adjacency and contacts.

The automation and transformation modules were validated through several case studies. Conformity is achieved when measurements across different anthropometric measures on the model deviate by less than 5% from the original tape measurement. 5 human body scans in “A” pose, with varying anthropometric measurements, took approximately 120 seconds to run on a standard workspace PC (16 GB RAM, 4 GB GPU, 160 GB SSD) and had a mean absolute error of less than 5%. The ContourCL-contour-based personalization successfully scaled available commercials HBMs (THUMS AM50 Pedestrian HBM, THUMS AM50 Occupant HBM, and GHBMC M50-O Occupant HBM) across 9 test cases, including scaling the HBMs to a target male anthropometry and examining uniform scaling by 10% and 20% of their skeletal bones. The whole personalization process took approximately. 60 seconds and was hence significantly faster than methods reported earlier, which can take hours. The increase in elements violating the Jacobian threshold of 0.7 was within 1.5% of the baseline models, thereby not necessitating time-consuming manual post-processing. Crucially, for robust models like THUMS, elements failing quality thresholds (Jacobian < 0.7) increased by less than 0.7%. The repositioning methodology was also validated by generating 7 distinct human gait cycle postures, again with excellent mesh integrity. Apart from mesh quality analysis, their numerical stability for injury prediction research was directly verified by a 3ms gravity-loading run and by deploying them in a 40 km/h dynamic LS-DYNA crash simulation for 200ms.

In summary, a robust, validated, and computationally efficient workflow, starting with the detection of anthropometric parameters from medical imaging, personalization of HBMs to defined antropomentric measures, and repositioning, has been presented. Automating the ContourCL-contour-based technique for creating person-specific FE-HBMs also enables deployment across multiple FE-HBM platforms. The personalized HBMs generated from this workflow are numerically stable in virtual crash simulations. By enabling the rapid generation of models that account for anthropometric diversity, this work provides a valuable tool for advancing vehicle safety research and developing more inclusive and effective occupant protection systems.