An Integrated Framework for Parametric Shape and Pose Reconfiguration of Finite-Element Human Body Models: Application to Highly Reclined AC-HUMs Occupants.

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I. INTRODUCTION

Virtual testing with finite-element human body models (FE-HBMs) is being incorporated into test protocols worldwide. Autonomous driving technologies are reshaping in-cabin layout, wherein zero-gravity and highly-reclined seats, as the featured trend, might lead to new safety issues due to the under-constrained occupant ride-down. HBM is a biofidelic surrogate to investigate reclined occupant biomechanics. However, classical medical image-based modeling methods do not naturally support reconfiguration of model shape and pose. We had proposed an HBM repositioning toolbox in the previous work [1], but it still cannot effectively handle the highly flexible spine as there are too many degrees of freedom (DOFs). Therefore, this study proposes a biofidelic algorithmic framework that comprehensively integrates controllable pose and morphology changes of HBM and demonstrates the efficacy with a group of highly-reclined occupant models in various body sizes.

II. METHODS

Coherent Spine-to-Global Repositioning Hierarchy and Algorithmic Implementations

Spine is the core of axial skeletons with over 100 DOFs in motion. It is nontrivial to define spine configuration with only few parameters as the system is *under-determined*. In this study, we leverage B-spline curves [2] to devise a low-dimensional representation of spine configuration with respect to a sparse set of control points. Vertebrae are translationally and rotationally aligned to the regressed centreline based on arc-length coordinates and local tangents. The baseline *AC-HUMs* M50 occupant model spine (in Chinese anthropometries, proposed by CAERI) is reconfigured into 25/45° reclined poses according to PMHS tests [3–4] respectively (Fig. 1(a)). Axial and appendicular skeletons, e.g., head, ribcage, and limbs, are hierarchically repositioned following an open-kinematics chain sequence (Fig. 1(b)), with soft-tissue deformation interpolated accordingly. The *morph-contact* algorithm [1] including preliminary interpolation, penetration elimination, and dynamic remeshing is employed to enhance the mesh regularity and consistency at the bone-flesh interface (Fig. 1(c)) during interpolation.

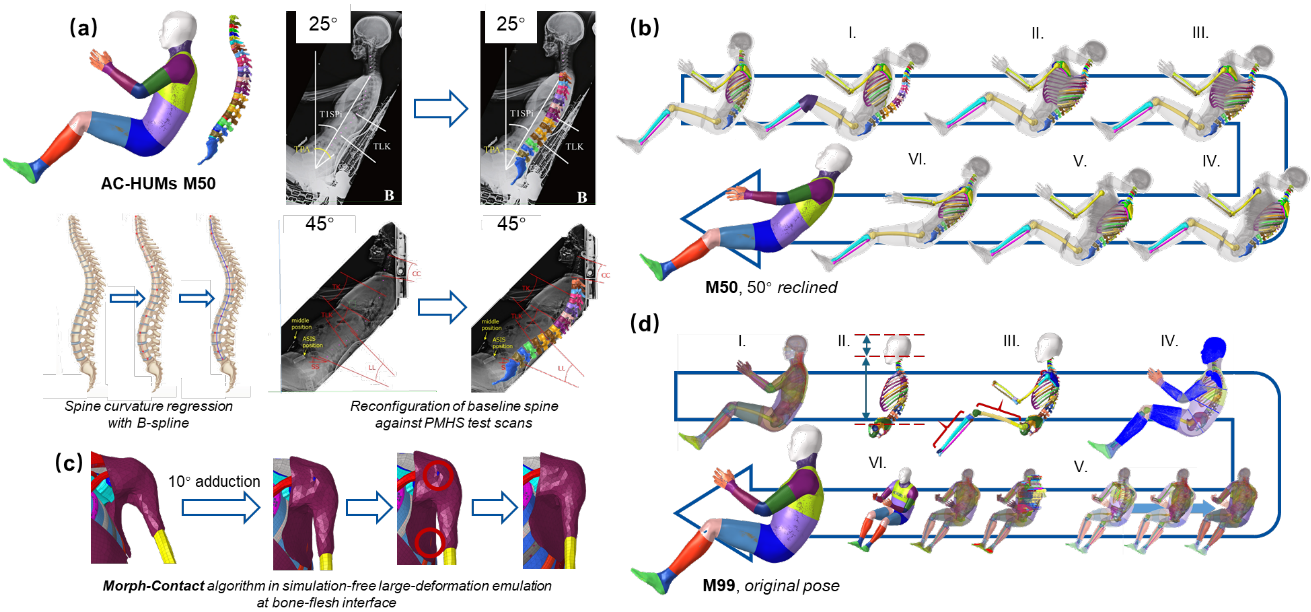

Figure 1. Technical roadmap of the framework: (a) Spine repositioning through spline-regression against images; (b) Spine-to-global repositioning hierarchy; (c) Mesh enhancements at interfaces; (d) Anthropometry-driven morphology change.

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Anthropometry-based Reshaping of HBM Morphology and Module Consolidation

The "*Human Dimensions of Chinese Adults*" (GB/T 10000-2023) standard documents demographics of Chinese anthropometry. We devise an anthropometry-to-morphology framework (Fig. 1(d)) to align the baseline model to target dimensions of interest, e.g., body height, sitting height, and chest perimeter, which consists of a series of anatomy/geometry-informed transformations, including head scaling/positioning, longitudinal and transverse scaling per rib, hybrid transformation of exterior, and segment-wise thin-plate spline-based mesh morphing. Computations compose a fully parametric, anthropometry-driven change of the heterogeneous structures.

The entire framework takes both pose and shape parameters as input, e.g., vertebral angles, joint angles, and longitudinal/circumferential dimensions of torso. The baseline is first morphologically reconfigured (Fig. 1(d)), and thereafter hierarchically repositioned (Fig. 1(a-b)). To combine the modules, all algorithms are written in a metadata-like routine. When morphology changes, only nodal coordinates are altered and can be easily re-implemented through ID retrieval, without having to reassign any featured landmarks or dimensions.

III. INITIAL FINDINGS

Figure 2 illustrates the generated multi-shape/pose models. The AC-HUMs M50 model is first morphed into 1^{st} and 99^{th} percentiles defined by the GB/T standard, with a drastic change of body height, sitting height and chest perimeter to 1528/1860, 827/1007, 770/1123 mm respectively. The multi-shape models are repositioned to reclined poses following the spine-to-global scheme (Fig. 1(a-b)), wherein the 25° and 45° spines are aligned to images [3–4] and another two angles, 30/50°, are inter-/extrapolated on the vertebral angle level. Other joint parameters are heuristically assigned accordingly to demonstrate/validate algorithm efficacy. On a i5-13790F/RTX4060Ti desktop platform, the entire pose reconfiguration takes about eight minutes. The output models are ready-for-simulation, with comparable mesh quality to the baseline (3D Jacobian > 0.22).

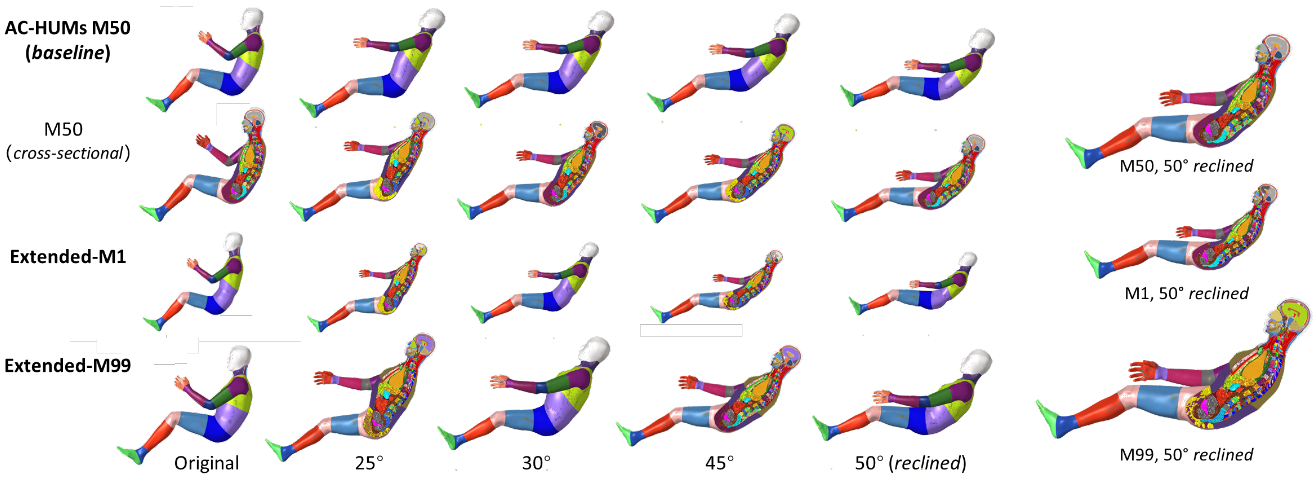

Fig. 2. Multi-shape/pose AC-HUMs occupant models parametrically generated following the integrated framework.

IV. DISCUSSION

We propose an integrated controllable reconfiguration framework for FE-HBMs. Anatomical structures, e.g., spine, limbs, and organs, are geometrically programmable on both shape and pose level, through measurable parameters in practice. The computations are fully automatic. However, the spine motion is now limited to the sagittal plane, and some attached structures like ribs are heuristically manipulated. In future, more morphological and kinesiological priors are expected to be incorporated with the benefit from technologies like generative AI to enhance model fidelity, and computational efficiency of the algorithms would be further optimised as well.

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VI. REFERENCES

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