STAPP CAR CRASH CONFERENCE
SHORT COMMUNICATION

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Leveraging Human Body Models of Varying Complexity for Computational Efficiency

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ABSTRACT – The objective of this study was to reduce the computational cost of human body model (HBM) simulations by developing a method to switch between models of varying detail during an event. One application is simulations involving active safety systems where the total simulation time can greatly exceed crash-only HBM simulations. We introduce an iterative morphing method to capture large changes in occupant position. A simplified HBM is used in the pre-crash portion of an event. Then, a detailed version of the same HBM is morphed to the final position of the simplified counterpart at the instant prior to the initiation of the crash. Each morphing step utilizes a second order regression and Gaussian correlation function. Simulation times for the pre-crash portion of the event were reduced by a factor of 29 times. The average coordinate differences for the head (2.4 mm), pelvis (4.1 mm) and thoracic (3.7 mm) CG's matched closely between the simulated target and the morphed model. For robustness, the repositioned, detailed HBM was simulated in a NCAP level pulse and completed the simulation without error.

INTRODUCTION

Active safety systems pose a challenge to occupant injury assessment through simulation. These technologies greatly extend the simulation window of interest, from the typical 150 msec crash event to 1 or more seconds. Computational human body models (HBMs) inform researchers on how the body may interact with safety systems, as well as the risks associated with these interactions (Guleyupoglu, et al. 2017a). Detailed HBMs can provide local occupant injury risk data, or restraint system data, however the computational cost of a 2000 msec or greater simulation is likely too great for practical use. However, a simplified version of the same model could be used in the pre-crash portion of an event providing a significant savings in compute time. This would require a means to switch from the simplified to the detailed occupant model at the time of initiation of the crash portion of an event.

The Global Human Body Models Consortium (GHBMC) average male models (M50) were used in this study. The detailed model was developed using a multi-modality imaging protocol and regional model development approach (GHBMC 2014). The simplified model was developed for computational efficiency, kinematic assessments and validated at the full body level for frontal plane impacts (Decker, et al. 2016, Schwartz, et al. 2015).

The objective of this study is to develop a method to switch between models with differing levels of detail.

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The feasibility of this approach is assessed with the GHBMC M50 simplified (-OS) and detailed occupant (-O).

METHODS

Model Preparation

The Global Human Body Models Consortium (GHBMC) M50-O (v4.4, 1.3M nodes, 2.2M elements, 76.8 kg) and M5-OS (v1.8, 295K nodes, 357K elements, 79.6 kg) were used in this study. Both models were gravity settled into the driver position of a generic frontal crash interior found in literature (Guleyupoglu, et al. 2017a). The interior is equipped with a seat, steering wheel and column, a rigid floor pan as well as a knee bolster restraint. Gravity settling occurred over a period of 100 msec and the models were then subsequently belted using the LS-PrePost v. 4.2 belt fitting tool (Figure 1). Both models were initially the same position.

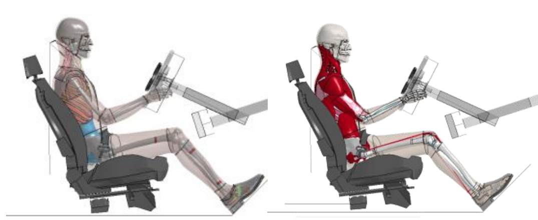

Figure 1. Seated positions of the M50-OS (left) and M50-O (right) models in the occupant compartment.

The pretensioner and retractor were not active during the pre-crash portion but were activated in the crash potion. The shoulder belt was modeled with a pretensioner and retractor system with peak loads of

1.5kN and 3.0 kN respectively. A stage 1+2 airbag was used in the simulation.

Pulse Design

The M50-O and M50-OS models were simulated in a braking pulse. A linear reduction in velocity occurred from 56.4 kph to 54.0 kph. The time over which this braking occurred is defined as the pre-crash portion of the event and was determined as per a previously published equation**.** It creates a linear profile based on the deceleration 0.4 G's) and the above predetermined change in velocity (Guleyupoglu, et al. 2017a). Thus, the crash phase occurred at 54 kph and was a scaled version of a generic NCAP-level pulse found in literature (Barbat, et al. 2013). The M50-O model was run for the entire pre-crash portion of the event in this case to generate a control.

Substitution Method

During the linear deceleration, the location of the M50-OS was tracked using 51 surface landmarks. These were used in the subsequent morphing process to reposition the M50-O model to match the position of the M50-OS model at given time points in the simulation. The M50-O model was iteratively morphed using a Kriging method which utilized a Gaussian correlation and second order regression functions (Lophaven, et al. 2002). The landmarks on the skin that were used were based on anatomical locations (Jolivet, et al. 2015) but were expanded to improve correlation. The automated process for iterative morphing follows the flow chart in Figure 2. In this methodological study, 21 states were used, or one state for every 10 msec in the pre-crash portion and resulted in 20 total morphs.

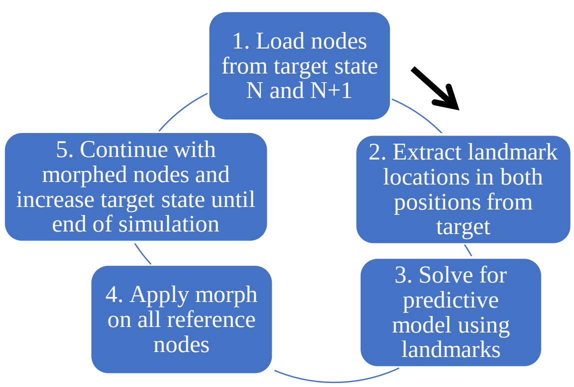

Figure 2. Flowchart of iterative kriging morphing method starting with loading nodes from state N and N+1 of the target model (M50-OS). The morphed or reference model in this case is the M50-O.

RESULTS

The M50-OS model had an average solution time of 0.5 min/msec in the pre-crash portion of the event compared to 14.4 min/msec for the M50-O (13.9 min/msec reduction). The morphed model demonstrated good agreement with the simulated model (Figure 3). The average deviation of the morphed surface was 6.8 mm and -5.5 mm with a standard deviation of 8.1 mm.

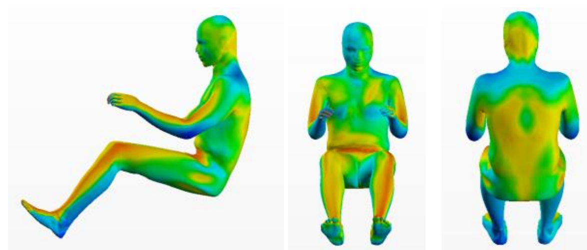

Figure 3. Surface deviation analysis of the morphed and simulated (used as reference) M50-O model. Warmer colors represent greater positive deviation (max: 34 mm) and cooler colors represent greater negative deviation (max 38 mm).

The bones of the morphed model also demonstrated good agreement but had some minor deformation from morphing at the distal end of the femur. The right knee had a difference in bone to bone distance between the femur and tibia of 0.45 mm in X and 0.7 mm in Z. The left knee had a difference of 2 mm in both X and Z. The distance from acetabulum to the femoral head was largely unchanged.

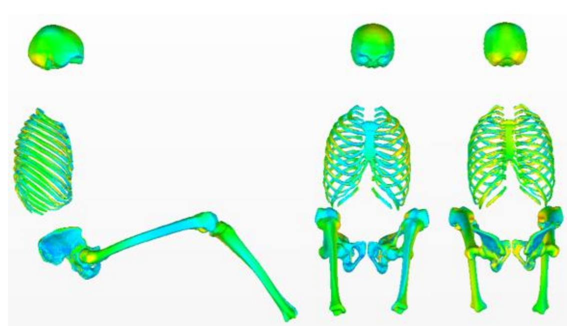

Figure 4. Bone deviation analysis of the morphed and simulated models. Warmer colors represent greater positive deviation. On average the models deviated 4.6 mm and -6 mm with a standard deviation of 8.1 mm.

The automated morphing method averaged 10 minutes for 21 consecutive morphed states on an Intel i7 4770K cpu. The overall geometry within the model was preserved. The model was also able to complete the crash event simulation post-morphing.

DISCUSSION

The computational cost to simulate the detailed M50-O model in the 202 msec pre-crash portion of the event was 48.5 hours (48 cores on a HPC system). This was reduced to 6 hours using the current method which consisted of running the M50-OS model and applying the morphing algorithm; a time savings of 42.5 hours (88% reduction). Longer pre-crash events will yield greater time savings. The morphing algorithm did not detrimentally reduce the element quality of the model. The mass of the model did decrease by 1.8 kg as a result of artifacts from the morphing process but can be further optimized through additional landmark selection. Multi-iteration morphing was part of the initial optimization to reduce artifacts.

Other morphing methods are available which can be used to reposition the model, such as the recently released open-source software, PIPER (http://www.piper-project.eu/). However, in this application, the target to reposition the model to must be quantitatively determined. The utility in the substitution method developed is that the final position is obtained through simulation of the M50-OS model, which has demonstrated a significant run time savings over the detailed model.

There are some limitations to this method which require further development. First, some disagreement was observed in the final position of the M50-OS model vs. the M50-O model at the close of the pre-crash portion of the event. The feet were further upward along the foot pan (about 10 mm) than the simulated M50-O model. The biggest difference was seen where the lap belt interacted with the model and this was on the order of 35 mm. We speculate that this can be optimized through landmark selection. Secondly, the model does have some distortions following morphing which would need to be sourced and reduced. One such area is the femur however this was largely limited to the distal end. There are also areas around where the lap belt and abdomen fat interacted that did not retain all of the deformation that occurred. Generally, any validated model with similar anthropometry could be used to generate the target position. Future work will assess whether pre-stresses must be tracked and work to improve landmark selection.

CONCLUSION

A method to switch between models of varying detail was developed and demonstrated an 88% reduction in the computational time required to solve pre-crash phase kinematics. The method yields a repositioned model which is close to the same model after simulating the full pre-crash portion of the event. The lap belt is the source of the greatest amount of deviation.

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