Computing Head Inertial Properties for Human Volunteers using a Parametric Head Model

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I. INTRODUCTION

The widespread deployment of automated crash-avoidance systems that can produce abrupt vehicle manoeuvres, such as hard braking, has increased interest in the behavioural responses of occupants in these scenarios over the past 10 years [e.g. 1-4]. Sustained interest in soft-tissue neck injury in low-speed rear-end crashes has also prompted considerable experimentation with human volunteers [5-6]. The head and neck kinematics obtained from these tests are often used to tune and validate musculoskeletal models [7]. However, the dynamic characteristics of the model heads are generally not well matched to the individual volunteers, which introduces additional uncertainty into the resulting estimates forces and moments in the neck, and the resulting estimates of muscle forces.

As part of a broader effort to improve subject-specific dynamic modeling, a parametric human head shape model was developed. Statistical shape modeling of the human body is a mature research area, but accurate measurement of the head is challenged by the ubiquitous presence of hair artifacts that distort the shape of the scalp area, particularly for female subjects. Park *et al.* (2021) combined manually measured scalp data from female participants with scans of bald men to introduce the first statistical head shape model with an accurate scalp based on a large, diverse dataset [8]. Park *et al.* (2022) demonstrated that this model, with data from 180 subjects, could be used to impute the scalp shape under the hair from a 3D scan of the face, ears, and neck [9]. In the present work, the statistical head shape model has been expanded to 610 subjects using geometry extracted from de-identified medical imaging (CT) studies obtained from the University of Michigan radiology archives under a protocol approved by an Institutional Review Board for human subjects' research (HUM00004842).

II. METHODS

Processing Pipeline

In the present work, we have developed a pipeline to create a subject-specific finite-element (FE) head model by morphing an FE template mesh. The process is illustrated in Fig. 1. A 3D scan is taken using any suitable scanner, which can include dedicated head scanners or more flexible handheld units. The hair should be pulled up and away from the face, neck, and ears, but does not need to be compressed. If possible, manual measurements of head length, breadth, and the distance from tragion to the top of the head should be taken using standard methods and instruments. These dimensions are not essential, but they can improve the accuracy of the shape estimation. The head shape model is fit to the data using an automated process that results in a homologous template mesh with 22k vertices and integrated landmarks. The THUMS 4 FE model head was prepared for this work by: (1) mapping the head shape model to the THUMS mesh; (2) improving the face shape of the THUMS mesh to be more realistic; and (3) recording the relationship between the mapped shape model template and the FE model nodes. Subsequently, the FE mesh can be immediately morphed to any other configuration of the head shape model, including those created by fitting subject scans. Note that this process can be easily applied to skin surface data extracted from CT data from post-mortem human subjects (PMHS). Mass properties, including centre-of-mass location and moments of inertia, can then be calculated immediately from the subject-specific FE model using a variety of software packages, including Hypermesh. The values in this paper were computed using custom Python code that combines the individual mass effects of each element.

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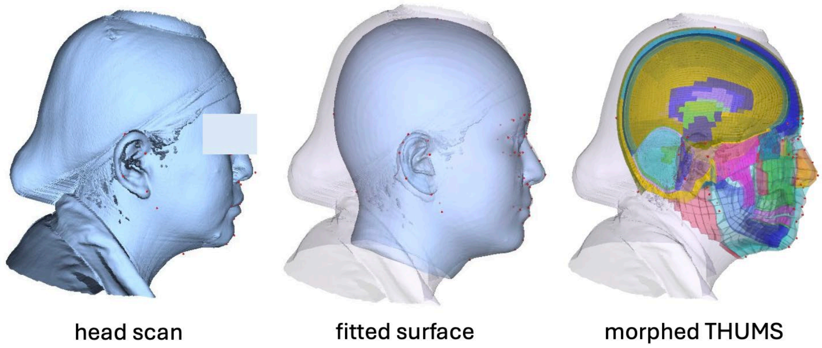

Fig. 1. Process for estimating volunteer head mass properties by fitting a FE head model.

III. INITIAL FINDINGS

A preliminary validation of the method was conducted using PMHS data from Albery *et al*. [10]. As part of a larger study of body segment mass properties, frozen PMHS heads were segmented and surface contours recorded with an optical scanning system. These surface scans are low quality, with large gaps, but the current method can readily fit across holes. Figures 2 and 3 show the computed masses and moments of inertia for six subjects about an axis system defined by the Frankfurt plane with an origin at the midpoint between the tragion landmarks. The fitted mass values were generally higher than measured, which may be due to loss of fluid in the PMHS heads during preparation. Reducing each fitted value by a constant 0.33 kg moved each estimate within 6% of the measured value. The fitted moments of inertia were well correlated with the measured values on all axes, with the largest discrepancy being 20% and most being less than 10%.

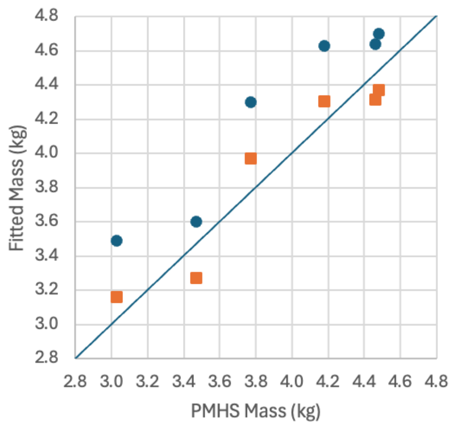

Fig. 2. PMHS head mass and estimates. Squares are the estimates after adjustment (see text).

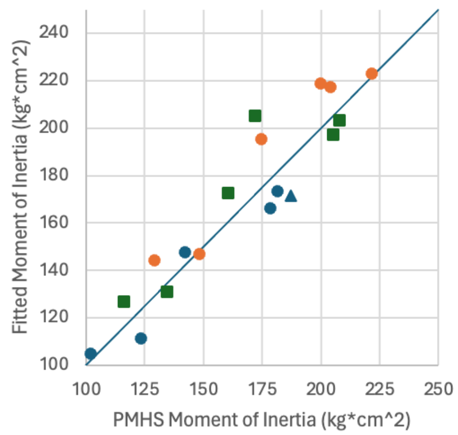

Fig. 3. PMHS moments of inertia and fitted estimates. I_xx, I_y, and I_zz are squares, circles, and triangles, respectively.

IV. DISCUSSION

This method shows promise for estimating the head mass properties of human volunteers. Further work to refine the bone dimensions (e.g. skull thickness) and material properties in the THUMS model might improve predictions. The accuracy of the method should be compared to estimates obtained using regression prediction from linear head dimensions [11]. The FE model morphing method readily generalises to any segment of the body and can be used to develop whole-body subject-specific models with accurate segment mass characteristics.

V. REFERENCES

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