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Modeling Active Human Muscle Responses during Driver and Autonomous Avoidance Maneuvers

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Abstract Integration of pre-crash and in-crash safety systems has a potential to further reduce car occupant fatalities and to mitigate injuries. However, the introduction of integrated safety systems creates new requirements for Human Body Models (HBMs) as occupant kinematics must be predicted for a longer period of time, in order to evaluate the effect of systems activated before the crash phase. For this purpose, a method to model car occupant muscle responses in a finite element (FE) HBM have been developed, utilizing feedback control of Hill-type muscle elements. The model has been applied to study occupant kinematics under the influence of autonomous and driver braking deceleration. Ongoing work aims at extending the model to be able to also capture human responses to lateral and oblique pre-crash loading.

Keywords active muscle · occupant kinematics · feedback postural control · human body model · finite element

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1 Introduction

With increasing computational power available, numerical simulation has become an important tool for all types of product development, especially in the automotive industry. To evaluate the risk of injury in a simulated vehicle crash, models of the occupants are needed. In physical testing this task is performed by mechanical models of the human, anthropomorphic test devices (ATD). Numerical models of ATD exist and are used extensively, but more detailed responses can be evaluated if the occupants are represented by an HBM, directly representing the anatomical structures and materials of the human body.

Even though HBMs more closely resemble the actual human body, many aspects of the human anatomy and mechanical properties of living tissue remains to be incorporated. One such feature is the inclusion of active musculature and control of the muscles, which has only to a limited extent been included in HBMs to date [1,3,4].

Emerging integrated safety systems has the potential to decrease impact severity through, for instance, autonomous braking [2,15] or steering [5]. Furthermore, sensory information and decision algorithms enable occupant restraint activation to start before impact[6,16]. The duration of and load level present in the pre-crash phase requires human active muscle responses to be taken into account as they will have a major influence on the kinematic response of the occupants. For the evaluation of these types of integrated safety systems, there is a need for the inclusion of actively controlled muscles in HBM.

2 Method

In our work, the THUMS version 3.0 AM50 occupant model [17] is used. Its anthropometry is based on the 50th percentile male reported by Robbins et al. [14] and it consists of approximately 68 100 solid elements, 75 700 shell elements and 3400 one-dimensional elements. The model contains rigid bodies (e.g., the vertebrae) and deformable bodies (e.g., the intervertebral discs, ribs, skin, and internal organs). For the simulations, the explicit FE solver LS-DYNA (LSTC Inc., Livermore, CA, USA) is used.

2.1 Muscle Implementation

A total of 394 Hill-type line muscle elements have been added to the THUMS; 178 for the cervical spine, 110 for the lumbar spine, 14 abdominal, and 23 for each upper and lower extremity (Figure 1). For each of the muscles, active muscle stress is computed according to [9]:

$$\sigma = (N_a(t) * f_v(v) * f_l(l) + f_{pe}(l)) * \sigma_{max} + \sigma_d \quad (1)$$

where *Na(t)* is the muscle activation level determined by the controllers, described in Section 2.2.

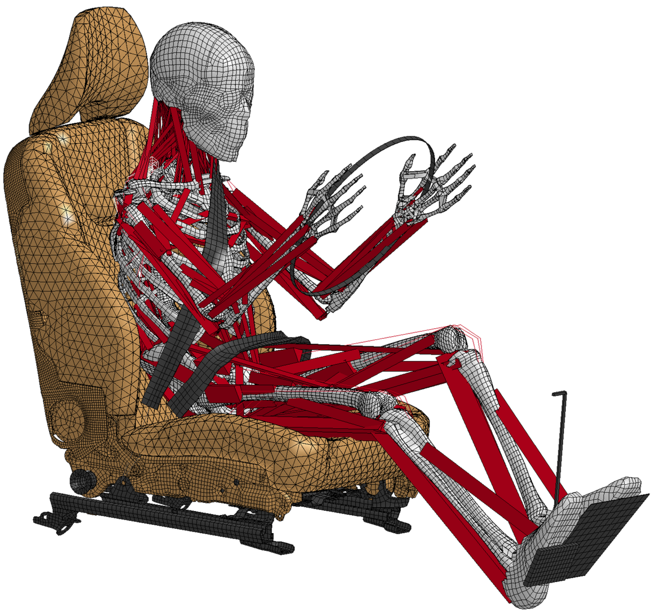

Fig. 1 Active HBM in a driver braking simulation [13], picture adapted from [9]. The soft tissues not shown to disclose the musculoskeletal structure of the model.

2.2 Muscle Implementation

In the maintenance of a reference position, postural control, the human central nervous system employs a feedback control strategy, i.e. stabilizing muscle activations are generated in response to external perturbations [7]. This is implemented for the FE HBM through the use of seven proportional, integral, and derivative (PID) controllers, as generic representations of muscle spindle feedback and vestibular reflexive stabilization.

The controllers use the angle of the head, neck, lumbar spine, and humerus shoulder relative to the vertical axis, and for the elbows between the ulna and humerus, to generate the control signals $u(t)$. These are torque requests that are actuated by the muscles of each controlled body segment, which are grouped as either flexors or extensors, and each receive a muscle activation level $Na(t)$ determined through closed loop control [9].

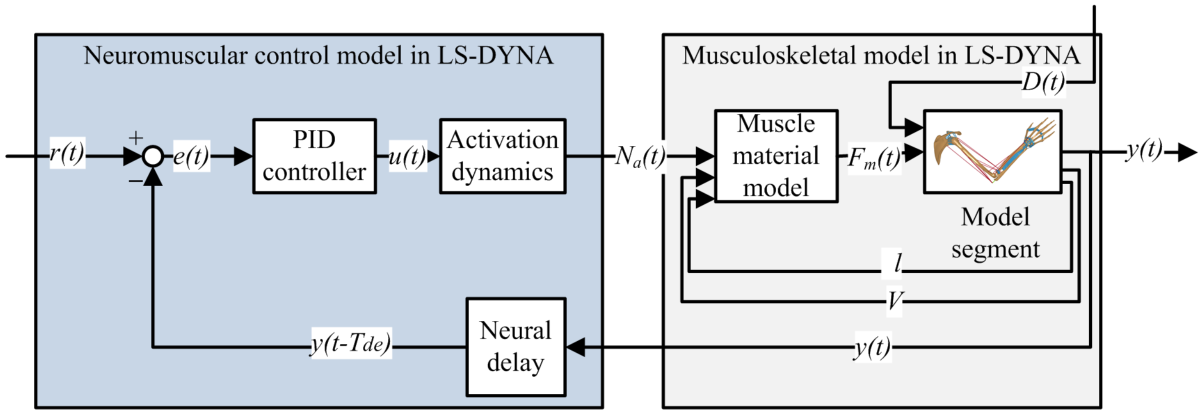

Fig. 2 Schematic representation of the neuromuscular feedback control model used in the Active HBM. Adapted from Östh [9].

3 Applications

The Active HBM and the feedback control method has been applied to study the response of the upper arm to impact-like pertubations [12], for modeling of car passenger responses in medium braking interventions [11]. Furthermore, the Active HBM was used to study driver responses to unexpected autonomous braking interventions in combination with reversible pre-tensioned restraints[10] and in driver voluntary braking [13].

4 Ongoing Work

The next step in this work is to extend the controller implementation to simulate postural control in omnidirectional load cases such as autonomous steering and braking interventions. This task is not trivial as it is not as clear in these load cases, in particular for the neck and trunk, which muscles are agonists and which are antagonists. Current research on volunteer muscle activation patterns in multi-directional perturbations show that various neck muscles have distinct directional dependence and muscle specific contraction levels [8]). It might be a feasible solution to modify the control signal so as to regulate actuation by individual muscles rather than agonist and antagonist groups. To validate the response of the modified HBM, volunteer experiments will be performed to gather data on the human kinematic and muscle response during steering and combined steering and braking maneuvers.

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