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OPTIMIZED 2D NECK MODEL FOR WHIPLASH INJURY SIMULATION

***Marta S. Carvalho*[1,2], *Ana P. Martins*[1], *Diamantino Henriques*[1], *J. F. A. Madeira*[3,4]**

[1] UNIDEMI, Universidade NOVA de Lisboa, Portugal

[2] Laboratório Associado de Sistemas Inteligentes, LASI, Portugal

[3]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal

[4] ADM, ISEL, Instituto Politécnico de Lisboa, Portugal

mip.carvalho@fct.unl.pt; apc.martins@campus.fct.unl.pt; dfm.henriques@campus.fct.unl.pt; aguilarmadeira@tecnico.ulisboa.pt

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1 INTRODUCTION

Whiplash injuries from rear-end vehicle collisions are a common cause of long-term neck pain and reduced mobility. Computational models such as the Efficient Neck Model (ENM-2D) [1] are effective for simulating neck dynamics during whiplash events but require refinement for better predictive accuracy. However, despite its success, the original model requires further refinement to enhance its predictive accuracy, particularly for more detailed injury risk assessment. Building on our previous work with the ENM-2D model, shown in Figure 1(a), this study aims to optimize the model using the Global and Local Optimization (GLODS) algorithm [2], which strikes a balance between accuracy and computational efficiency. For context, the TNO-Human Body Model (TNO-HBM) [3] is a validated numerical framework widely employed to simulate occupant responses in rear-impact collisions. By applying GLODS, we enhance the model's capability to simulate neck dynamics and predict cervical spine injuries with greater precision.

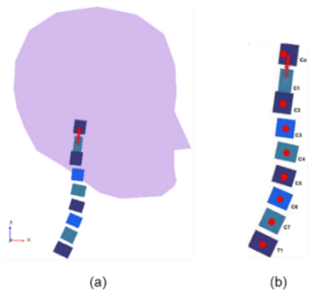

Figure 1 – ENM-2D: (a) Complete model. (b) Detail of the cervical spine model.

2 METHODOLOGY, SIMULATION AND RESULTS

In the ENM-2D model, the cervical spine is represented by interconnected rigid bodies from C1 to C7, with non-linear springs and dampers simulating biomechanical properties, as shown in Figure 1(b). Using raw data from experiments with cadavers [4], a discrepancy arose between this model and the TNO-HBM during simulations, prompting an identification process to refine the ENM-2D model. To address this, the GLODS algorithm was applied to optimize the biomechanical parameters, leading to a marked improvement in kinematic accuracy. A key advantage of GLODS is its derivative-free approach, relying solely on objective function evaluations.

At the start of the simulation, the kinematic behavior of the ENM-2D model closely resembled that of the TNO-HBM reference. However, after approximately 180 ms, significant differences between the two models began to emerge. As shown in Figure 2, the discrepancy reached its maximum towards the end of the simulation, with the largest deviation being around 70° in the head's rotational angle and in the head’s rotation relative to the T1 vertebra.

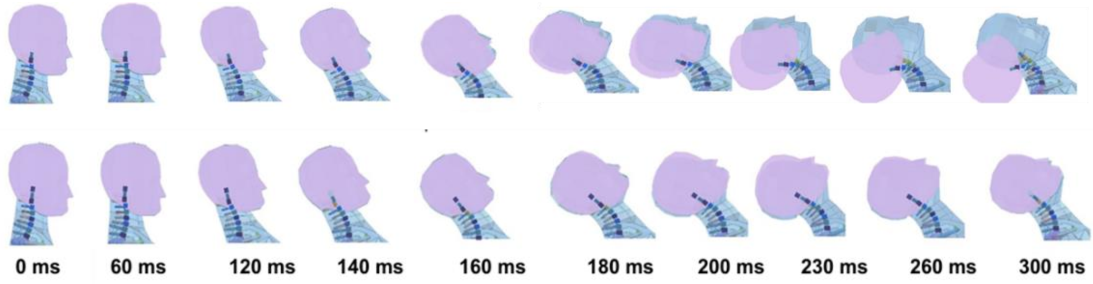

Figure 2 – Kinematics: ENM-2D (initial on top and final on bottom) and TNO-HBM (reference). After the optimization, both models’ frames overlap, and ENM-2D is displayed in the front.

To address these discrepancies, an identification process was employed to fine-tune key parameters of the ENM-2D model using a sequential optimization approach. The design variables identified in this process were the stiffness of the springs and the damping coefficients, which influence how the neck responds during a whiplash event. The objective was to minimize the Root Mean Square (RMS) deviation between the simulated kinematics of the ENM-2D and the reference kinematics provided by the TNO-HBM, focusing on head and neck angular displacements during a rear-end collision. Following the optimization process, the updated ENM-2D model showed a significant improvement in its kinematic accuracy. As depicted in Figure 2, the final version of the ENM-2D model exhibited a much closer correspondence with the TNO-HBM reference model. The discrepancies between the head displacement and body rotation in both models were substantially reduced, as expected.

3 Final Remarks

The integration of GLODS in the optimization process has enabled the model to strike a balance between improved accuracy and computational efficiency, making it highly suitable for large-scale simulations. As a result, the enhanced ENM-2D model not only improves our ability to predict injury risks but also assists in the design and optimization of vehicle safety systems aimed at reducing whiplash injuries.

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