

A Statistical Surrogate-Based Bayesian Approach to Calculate Brain Injury Criteria

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Abstract

Traumatic brain injuries (TBI) lead to approximately 50,000 fatalities annually in the US alone. Finite element (FE) computational models of the head and brain are extensively used to study the effects of impact loading and develop protective gear. A computational model, however, is only as good as the underlying constitutive equations describing the material behavior of the various constituents, especially the soft matter. The experimental data that underlie soft tissue constitutive models show significant variability or uncertainty, which is often ignored. This brings into question the reliability of the computational models.

The overall goal of this work is to develop a framework to obtain reliable computational models where the uncertainty in material behavior is taken into account. We consider a Bayesian approach for the inverse problem of material parameter estimation as an alternative to traditional deterministic inverse methods. This is a natural choice given the large amount of uncertainty inherent to soft tissue mechanical testing.

Specifically for the case of brain tissue, a stochastic nonlinear visco-hyperelastic constitutive model is developed, with contributions from long-term viscoelasticity, short-term viscoelasticity, and hyperelasticity. The distribution of the material model parameters is obtained using the Bayesian framework utilizing experimental data from uniaxial compression and relaxation tests on porcine brain tissue. This material model is implemented into the commercial finite element solver LS-DYNA using its UMAT interface.

Traumatic brain injury caused by impact loading from vehicle crash is simulated using a finite element model of the human head where the stochastic constitutive model is used to represent the soft tissue in the brain. A maximum principal strain-based injury criterion is used to assess the severity of the brain injury. The uncertainty in the material model parameters is non-intrusively propagated to the injury criterion using a Bayesian Gaussian process surrogate of the finite element model to avoid computationally expensive simulations. This enables us to calculate the probability that an injury tolerance is reached for a given impact loading. This probabilistic method can be used to further simulate injuries and calculate various injury criteria with higher fidelity.