REAL-TIME DEFORMABLE MODELS OF NON-LINEAR TISSUES BY MODEL REDUCTION TECHNIQUES

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ABSTRACT

Biological soft tissues show highly non-linear behaviour and they are usually modelled using finite element method. The real-time simulation of human tissues is of particular interest with applications in surgical simulators or minimally invasive surgery simulation. In such user interactive applications it is commonly accepted that a minimum bandwidth of 20-60 Hz for visual feedback and a 300-1000 Hz for haptic display is necessary. The obtained solution using such FE methodology is very accurate, but the amount of computation is significant, prohibiting interactive applications for models with more than a couple of hundred elements. This is so since at each time step a new stiffness matrix is usually computed in a Newton-Raphson scheme, for instance, and then a large system of equations must be inverted that is computationally demanding.

In this paper a new technique for the simulation of non-linear tissue behaviour is introduced. It is based on a model reduction technique known as Proper Orthogonal or Karhunen-Loève Decomposition. In model reduction techniques global basis functions are used instead of traditional, FE, piece-wise polynomials. Firstly a detailed off-line simulation is performed using FE software (or using experimental data if available). From these data relevant information about the tissue behaviour is extracted and it is then applied to construct a very fast Galerkin method with very few degrees of freedom. To show the performance of the method we have chosen to simulate the behaviour of the human cornea although the technique is equally applicable to any other soft tissue. We present the simulation of the palpation the cornea and study the limitations and future needs of the proposed technique. In all the examples calculations ran at about 400-1000 Hz, thus verifying the requirements of real-time computation.

KEY WORDS: non-linear behaviour, biological tissues, model reduction techniques, proper orthogonal decomposition, Karhunen-Loève Decomposition