

Flexible Mass Spring Method for Modelling Soft Tissue Deformation

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Abstract- Soft tissues in general display two phases of deformation, linear during small deformation and nonlinear during large deformation. Researchers have been facing difficulty to model the soft tissue deformation mainly due to the two phases of deformation. Simplification often the solution in which either linear or nonlinear part is considered. On top of that, the nonlinearity of the deformation cannot be simply described by polynomial or exponential functions which have increased the complexity of the simulation process. This study explores an alternative simulation approach from the standpoint of Mass Spring Method (MSM). The proposed MSM model is developed using conical spring methodology which allows the MSM model to have different stiffnesses at different displacements during deformation. The stiffness variation creates flexibility in the MSM model to simulate any linear and nonlinear behaviors. This paper also analyzed the influence of several conical spring parameters on overall deformation. The experimental findings demonstrate that the proposed model produces deformations that are consistent with real and phantom soft tissue deformations. After the parameters are optimized, the average relative error is less than 5%.

Indexed Terms- Soft tissue deformation, nonlinear MSM, conical spring methodology

I. INTRODUCTION

The most common methods for modeling soft tissue deformation are the Finite Element Method (FEM) and the Mass-Spring Method (MSM). The first approach is based on continuum mechanics, which governs elastic behavior in a continuous medium made up of linked volumes. FEM-based implementations are difficult. Although it depicts precise and realistic performance, FEM models are extremely detailed, intricate, and computationally demanding. The second approach, on the other hand, considers elastic behavior on a discrete basis. It divides a model into separate mass points linked together by springs. Traditional MSM models, in general, are controlled by significantly simpler mathematics than the FEM model. As a result, it provides simplicity and real-time interaction.

Numerous works have been published in the literature that aim on improving the MSM model in terms of modeling nonlinear deformation. Cooper and Maddock [5] presented one of the early nonlinear MSM models. They used a quadratic function to characterize the nonlinear behavior of soft tissues. The displacement function of a nonlinear spring was developed using the quadratic function. The method's primary disadvantages were that it was only applicable to two-dimensional objects and that no validation data was provided. Teschner et al. [6] went on to characterize the nonlinear behavior of their MSM model by varying the stiffness of the spring. Teschner et al. employed a quadratic function on the spring stiffness rather than a quadratic function on the displacement function, as Copper and Maddock did. They provided three stiffness functions for the user to choose from: linear, small nonlinear, and large nonlinear. Their methodology, however, is only viable for stiffness coefficients that converge to linear during small deformation. Furthermore, Luo and Xiao [7] used Duffing's equation to characterize the nonlinearity. It is a second-order nonlinear differential equation. Their investigation was successful in simulating nonlinearity, but no validation procedure was reported. Cui et al. [8] used the Duffing's