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Optimization of Hyperelastic Constitutive Model Coefficients for Soft Tissue by Imperialistic Competitive Algorithm Based on Experimental Data

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ABSTRACT: The main target of this study is identification of the constitutive model of a soft tissue. For such a purpose a robotic tactile device (Robo-Tac-BMI) was used for breast tissue examinations and stress versus strain was collected for every test point during loading and unloading processes. Utilizing accurate experimental dataset for mechanical modeling of the tissue in conjunction with an optimization algorithm provides a reliable constitutive model of tissue's mechanical behavior. Eight major hyperelastic models were adapted to the stress-strain data to find the most compatible constitutive equation applicable to the soft tissue mechanical behavior. For this purpose, a new optimization algorithm called imperialist competitive algorithm which is based on social and political strategy was used. The novelty of the present study is producing a realistic mathematical model with high accuracy of the soft tissue based on experimental data. The achieved hyperelastic model can be used for prediction of mechanical behavior of the breast tissue in surgery simulation for assistance and educational purposes. Other application of this model is clustering of healthy and cancerous tissue which facilitates the surgeon's task in the diagnosis procedure. This application also makes the diagnosis procedure almost independent of using imaging techniques or performing biopsies. This model is useful in distinguishing cases where the soft tissue has altered from normal situation like tumors and cancer attacks.

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1- Introduction

Cancer is a name for more than 100 diseases and the common point of them is abnormal increasing growth of cells in various locations of body. Early diagnosis is an important determinant of increasing probability of surviving and better treatment. On the other hand, the engineering has led to greater accuracy and reduced costs and human errors when it entered any fields. Both experimental and numerical approaches in mechanical engineering have helped medicine to advance healthcare treatment, including diagnosis, monitoring, and therapy since last century, especially in soft tissue cancer treatments [1]. In the field of cancer detection, the primary step in numerical approach is modelling of biological tissues while considering exact mechanical properties. In recent years many researches have focused on modeling of biological tissues. For a reliable modelling, we have to find a perfect constitutive equation. The hyperelastic models have been proved to be better fitted to soft tissues [2]. Thus, in this endeavor, we intend to evaluate most of possible hyperelastic models to find the best one.

According to nonlinear behavior of the hyperelastic equations, it would be better not to use linear optimization methods to detect the best material's mechanical constants. Here, a new optimization method with least calculations and time expenditures which was introduced by Atashpaz [3] and named Imperialistic Competition Algorithm (ICA) was implemented. This algorithm is based on social and political strategy that has demonstrated its high speed and precision in finding the most appropriate situation of the answers which is strain versus stress datasets.

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2- Methodology

2- 1- Experimental data

In this study, for precise loading of the soft tissue a robotic device (Robo-Tac-BMI) was used [4, 5]. Details of the device are shown in Figure 1.

Figure 1. Design of a tactile sensing robot called Robotic Tactile Breast Mass Identifier (Robo-Tac-BMI)

2- 2- Imperialistic Competition Algorithm

Artificial neural networks are capable to learn a pattern from experience and improve it. The significant privileges of neural networks are the capability of processing a large amount of data and also its ability to predict the model from training data.

Radial Basis Function (RBF) is the one of most popular ANNs which enable proper generalization, amelioration of input perturbations and ability of online learning. RBF networks are neural networks methods which are based on localize basis functions and iterative function approximation. In calibration process, neural network is applied for prediction of the parameters twice. Initially, the five-hole probe is installed within the wind tunnel and its pitch and yaw angles are varied and the static and total pressure coefficients as well as pitch and yaw pressure coefficients are calculated. At the first implementation of neural network, the pitch and yaw pressure coefficients obtained in the wind tunnel calibration are selected as the input parameters for learning the neural network, introducing the pitch and yaw angles from calibration in the wind tunnel as the output parameters. After proper learning neural network, the obtained pitch coefficients and yaw coefficients from measuring data in the experiment are fed into the neural network. The predicted outputs are the pitch and yaw angles of the flow that passed the five-hole probe. At the second step, pitch and yaw angles of calibration at the wind tunnel are fed as the input parameters and the total and static pressure coefficients will be as output parameters of learning neural network. After suitable learning neural network, the calculated pitch and yaw angles of first step are imported to the neural network. The generated outputs are the total and static pressure coefficients of flow that passed the five-hole probe. Finally, from the measured total and static pressure coefficients, three components of the local velocity vectors can be calculated.

2- 3- Constitutive Models

Hyperelastic or Green elastic constitutive equations are often used for soft tissue mechanical behavior modeling. In these equations, the strain energy density (W) is related to deformation gradient (F) or three invariants of left Cauchy-Green deformation tensor I_1, I_2, I_3 or principal stretches λ_1, λ_2, λ_3. Attard [6] explained that we can use following relation for calculation of engineering stress (σ).

$$\sigma = \lambda \frac{\partial W}{\partial \lambda} \quad (1)$$

In this paper, 8 models of the most widely used hyperelastic models were examined which include Neo-Hookean, Moony-Rivlin, Polynomial, Ogden, Fung, Yeoh, Gent and Arruda-Boyce. Table 1 shows these 8 constitutive equations.

Table 1. Strain energy density function of hyperelastic models

Row	Model	Material Constants
1	Neo-Hookean [7]	1
2	Moony-Rivlin [8]	2
3	Polynomial, n=2 [9]	5
4	Ogden, n=3 [10]	6
5	Fung [11]	3
6	Yeoh [12]	3
7	Gent [13]	2
8	Arruda-Boyce [14]	2

3- Results and Discussion

All proposed hyperelastic models were applied on experimental in vitro data which are collected from a patient examined by the Robo-Tac-BMI. There are two sets of clinical data, one for loading test and another for unloading test. ICA was utilized with Least Squares (LS) cost function and some of outlier data were passed up to reach the best material parameters for each hyperelastic model. Figure 2 displays the 2nd order polynomial curve fitted to the loading experimental dataset compared to Yeoh model [12] and Figure 3 shows 2nd order polynomial curve fitted to the unloading dataset but compared to Fung model [11]. Experimental data are shown by discrete point markers on the graphs.

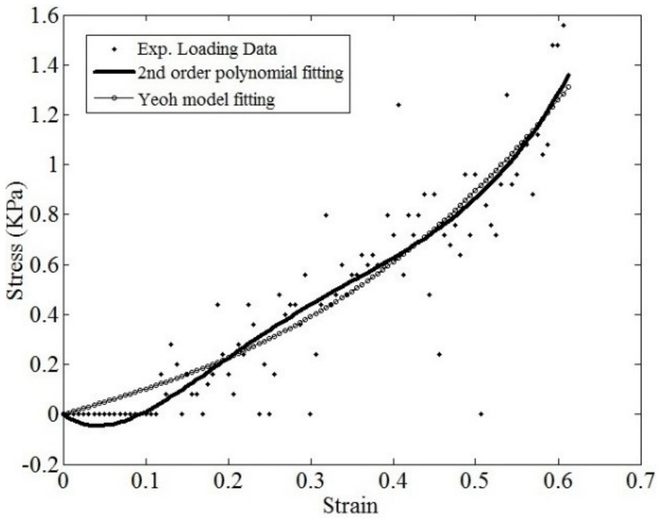

Figure 2. Experimental data in loading test with 2nd order polynomial model fitting

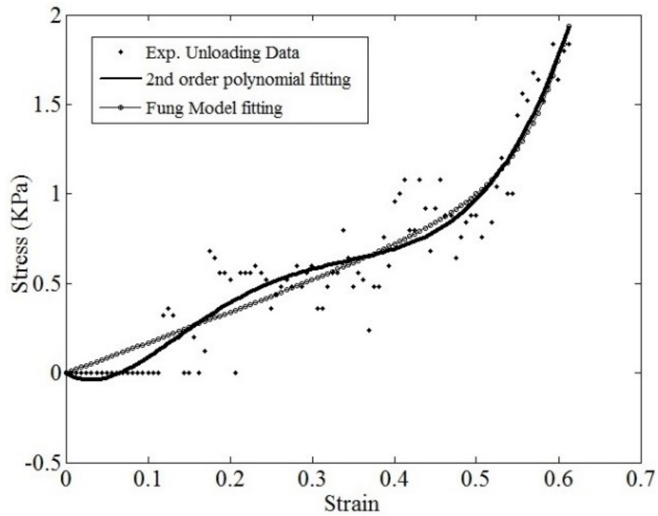

Figure 3. Experimental data in unloading test with 2nd order polynomial model fitting

4- Conclusions

In this paper, a robotic device equipped with an indentation probe was utilized to examine the soft tissue. Stress versus strain pattern was derived for a patient. Eight mechanical models were selected to provide a hyperelastic behavior for the breast tissue. Due to the wide range of stress-strain data, a social-based optimization algorithm was selected to achieve coefficients of the models with the least error and highest accuracy. Results showed that the 2nd order polynomial hyperelastic model was best fitted to the experimental datasets in both loading and unloading of the tissue.

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