Identification of nonuniform physical parameters through measurement of inner deformation

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***Abstract*— This paper describes a method to identify nonuniform physical parameters through measurement of inner deformation. We identify physical parameters by deforming an unknown parameters object using a known parameters object. We evaluate our method in simulation and experimentally.**

I. INTRODUCTION

Physical parameters identification of biological tissues is required for surgical simulation and operation planning. Biological tissues deform nonuniformly because they have different physical parameters at different parts. There is not any method to identify physical parameters of such kinds of soft objects. We proposed a method to identify physical parameters through measurement of inner deformation using ultrasonic, CT and MRI[1]. This paper describes evaluation of our method in simulation and experimentally.

II. THE METHOD OF PHYSICAL PARAMETERS IDENTIFICATION

In FE modeling, an object is described by a set of tetrahedras. Let T^p be one tetrahedra, of which vertices are P_i, P_j, P_k and P_l. Deformation of tetrahedra T^p is described by the displacement of four vertices $\boldsymbol{u_i}$, $\boldsymbol{u_j}$, $\boldsymbol{u_k}$ and $\boldsymbol{u_l}$. Each tetrahedra has different Lame's constants. Lame's constants of tetrahedra T^p are described by Young's modulus E^p and Poisson's ratio ν^p as follows:

$$\lambda^p = \frac{\nu^p E^p}{(1+\nu^p)(1-2\nu^p)}, \qquad \mu^p = \frac{E^p}{2(1+\nu^p)}. \tag{1}$$

The deformation of tetrahedra T^p yields a set of elastic forces exerted at its vertices:

$$\begin{bmatrix} \boldsymbol{f}_i^p \\ \boldsymbol{f}_j^p \\ \boldsymbol{f}_k^p \\ \boldsymbol{f}_l^p \end{bmatrix} = \boldsymbol{K}^p \begin{bmatrix} \boldsymbol{u}_i^p \\ \boldsymbol{u}_j^p \\ \boldsymbol{u}_k^p \\ \boldsymbol{u}_l^p \end{bmatrix}, \tag{2}$$

where $\boldsymbol{f}_i^p$ is an elastic force at vertex P_i. Partial elastic matrix $\boldsymbol{K}^p$ is given by $\lambda^p \boldsymbol{J}_\lambda^p + \mu^p \boldsymbol{J}_\mu^p$, where $\boldsymbol{J}_\lambda^p$ and $\boldsymbol{J}_\mu^p$ are partial connection matrices, which are constant matrices during deformation.

The basic idea of physical parameters identification is that physical parameters are identified by pushing an unknown parameters object using a known parameters object. Physical parameters mean Young's modulus and Poisson's ratio. Physical parameters of a known parameters object are measured by compression test in advance. The known parameters object contacts with the unknown parameters object as illustrated in Fig.1. The equilibrium at the i-th nodal point P_i is described as follows:

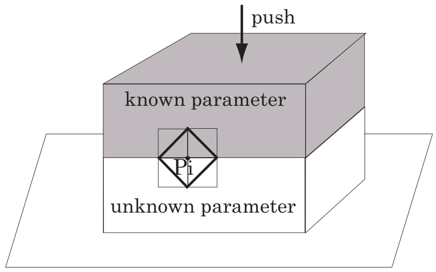


Fig. 1. The method of physical parameters identification

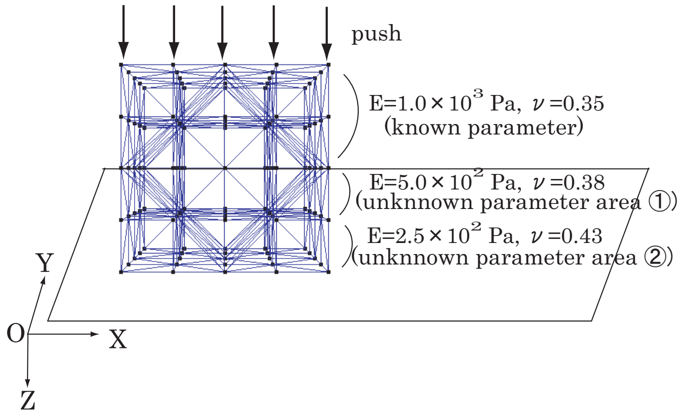


Fig. 2. The size of the object in simulation

$$\sum_{p\in U_i} \boldsymbol{f}_i^p = -\sum_{p\in K_i} \boldsymbol{f}_i^p, \tag{3}$$

where K_i is a set of tetrahedras which physical parameters is known and U_i is a set of tetrahedras which physical parameter is unknown. Note that equation (3) is linear with respect to Lame's constants of unknown parameters objects by substituting the result of deformation measurement. Young's modulus and Poisson's ratio are calculated using equation (1).

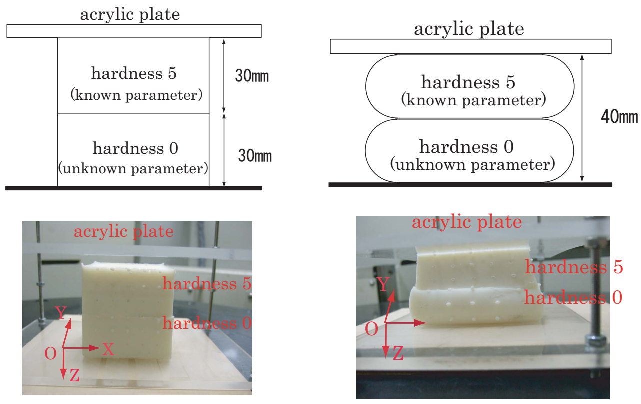
III. EVALUATION IN SIMULATION

In simulation, Young's modulus E and Poisson's ratio ν are set as illustrated in Fig.2. Mesh of model of an object is symmetric. The size of the object is 0.04×0.04×0.04 m and

TABLE I

THE RESULT OF PHYSICAL PARAMETERS IDENTIFICATION IN SIMULATION

	true value		result		error [%]
	E [Pa]	ν	E [Pa]	ν	
area	2.50×10^2	0.43	2.51×10^2	0.43	
area	5.00×10^2	0.38	5.18×10^2	0.32	1.37×10^{-2}



(a) initial state

(b) deformed state

Fig. 3. Soft objects in initial and deformed states

the length of each edge is 0.01 m. Considering that the object deforms on the floor, Constraint Stabilization Method is applied to constrain the object. The whole top face of the object is pushed by 0.00 m in X and Y direction and 0.01 m in Z direction. The displacement data from initial to deformed state is used in identification. Assuming that the upper half of the object is uniform known parameters object and the lower half is nonuniform, unknown physical parameters are identified. Table I shows the average parameters value of tetrahedra that has same parameters. The error is less than one percent.

IV. EVALUATION IN EXPERIMENT

A known parameters object is made from Hitohada gel hardness 5 (standards of face or arms). An unknown parameters object is made from Hitohada gel hardness 0 (soft as a baby's skin or an abdomen). They are soft urethane resin which have very similar softness and feeling of human skin. The soft objects are made by blending base resin and the hardening agent and pouring it into the mold. Strings are tensed crisscross in a mold and markers are placed at crossing points. Washers of 2.8 mm diameter and 0.3 mm thick are used as the markers. They can be implanted in the soft objects by unmolding them after they harden. The both objects are $60 \times 60 \times 30$ mm and the markers are placed at 10 mm intervals. Putting the hardness 5 object on the hardness 0 object, both objects are pushed until they reach the height 40 mm by an acrylic plate as illustrated in Fig.3. The inner deformations at the initial and deformed state are measured by a CT device. The resolution of CT is 0.29 mm in X and Y direction and 0.5 mm in Z direction. The deformation of the soft objects are measured by binarizing CT images and extracting the washers.

TABLE II

PHYSICAL PARAMETERS OF SOFT OBJECTS

	E [Pa]	ν
hardness 5	2.22×10^5	0.33
hardness 0	1.25×10^5	0.44

TABLE III

THE RESULT OF PHYSICAL PARAMETERS IDENTIFICATION IN EXPERIMENT

compression test		result		error [%]
E [Pa]	ν	E [Pa]	ν	
1.25×10^5	0.44	1.55×10^5	0.29	5.51×10^{-2}

Young's modulus of the hardness 5 and 0 objects are measured by compression test. Compression testing machine used in this experiment cannot measure transversal strain and Poisson's ratio cannot be computed. Poisson's ratio is computed using the value of longitudinal and transversal strain measured from CT images in initial and deformed state. Table II shows the values of physical parameters of the soft objects used in this experiment.

Assuming that the hardness 0 object is the unknown parameters object and the hardness 5 object is the known parameters object, unknown parameters are identified. Mesh model is the same as the one in simulation. Table III shows the result of physical parameters identification. The error is bigger than the one in simulation but it is also less than one percent.

In identification of nonuniform physical parameters objects such as biological tissues, the deformation is measured by extracting feature points in tissues. Feature points in tissues are obscure so the accuracy of identification will get worse than the result of this experiment. It is needed to find the suitable mesh model and softness of a known parameters object compared to an unknown parameters.

V. CONCLUSION

In this paper, we evaluated a method to identify nonuniform physical parameters in simulation and experimentally. In simulation, we identified nonuniform physical parameters using the method and presented it is valid. In experiment, we identified uniform physical parameters of a soft object through measurement of inner deformation. We are going to make a nonuniform soft object made from Hitohada gel and identify physical parameters. We are also going to identify physical parameters of biological tissues.

REFERENCES

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