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Feature Quantification of Material Softness Perception Using the Force-Displacement Relationship*

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***Abstract*— To establish haptic interchangeability between ordinary materials and metamaterials, the FDDF (Force-induced Displacement Distribution Function) has been proposed for quantifying material properties. This paper describes how material softness is quantified using the FDDF.**

I. INTRODUCTION

The FDDF (Force-induced Displacement Distribution Function) is an input-output relationship that can represent the physical features associated with the haptic perception of a material [1]. Concrete expression of the FDDF depends on the mode of interaction with the object [2]. This paper describes the implementation of the FDDF for the case of pressing a soft object to quantify the features pertaining to material softness perception and reports on the substitutability of an ordinary object by a metamaterial.

II. PROCEDURE FOR COMPUTING FDDF (PRESS)

In the proposed method, a force-displacement relationship is adopted to represent the FDDF when a soft object is pressed. To represent the force-displacement relationship with a small number of parameters, principal component analysis (PCA) is used to construct an appropriate basis.

Force-displacement curves for various materials can be obtained using hardness testing machines or computer simulations. The round trip displacement is divided into a going displacement and a returning displacement.

As a pre-processing step, the measured M Force-displacement curves are resampled with a fixed number of samples N to compensate for differences in the number of samples due to different measurement conditions. Each force-displacement (F-D) curve is represented as a series of normal forces.

To focus on the profile of the F-D curves, the force and stroke of each curve are normalized by the maximum value of the normal force and the maximum value of the push-in amount, respectively. Then, for each normalized push-in amount, the average value of all data is subtracted. The data obtained in this way are subjected to PCA to obtain a basis function suitable for representing the F-D curve.

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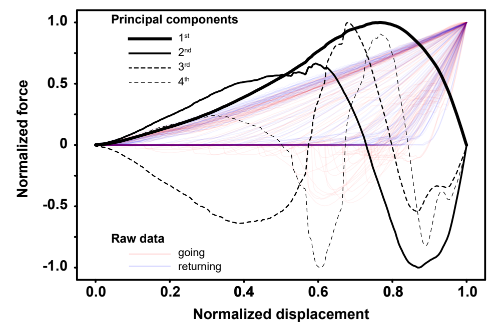

Fig. 1. Computed principal components with raw measurement data.

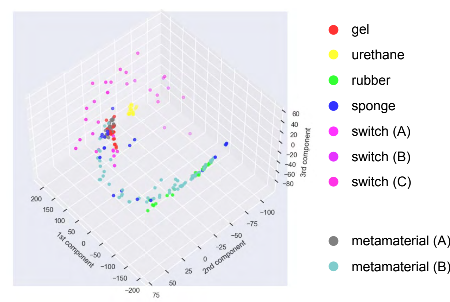

Fig. 2. 3D visualizations of the principal component scores.

III. MEASUREMENTS AND RESULTS

We measured the F-D relationship of the materials using a three-axis force sensor (YAWASA MSES5012-1-SL, Tec Gihan, Kyoto, Japan). The diameter of the spherical contactor was 30 mm. A 115 F-D curves of ordinary materials, including gels, urethanes, rubbers, sponges, and several types of push switches, and 103 curves of 3D-printed materials with different structures were obtained.

Fig. 1 shows the computed principal components with raw measurement data. The contribution ratios of the first four principal components are 89.2%, 6.9%, 2.0%, and 0.63%, respectively. Fig. 2 is a scatter plot of the principal component scores of the measured materials. From the overlapping areas of several types of materials (gels, sponges, and rubbers) and metamaterials, we can see that the softness of some gels, sponges, and rubbers can be expressed by 3D printing by changing the structure of the metamaterials.

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