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A 3D-printed Haptic Material Library for Quantifying the Force-Displacement Relationship*

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Abstract— **3D printing technology enables us to develop a composite shape of complex structures. This study describes the methodology of how haptic materials are developed using 3D printers. We present a material library to study haptic softness and texture perception.**

I. INTRODUCTION

Haptic material perception of an object determines its value. One can estimate the freshness of an apple by grasping it. Similarly, one can predict the quality and the function of a commercial product by touching it, although the haptic impression does not necessarily reflect its value. This is a motivation for why the study of haptic material perception is interesting, especially for luxury products in the fashion, the commercial electronics, and the automotive industry.

A 3D printer is a haptic display. Since the first proposal of personal fabrication, the advancement of the 3D printing technology allows us to develop a product with high spatial resolution. Recent 3D–printing technology advances for developing the composite structures of inner structure, which is called metamaterials. These 3D–printed materials are widely used as tactile stimuli in experimental psychology.

The advantage of using 3D printers in experimental haptics is that we can easily manipulate several parameters of tactile stimulus, such as braille dot size, the spatial frequency of gratings, and the density of a 3D–printed object. Researchers can systematically control the causal relationship between mechanical parameters of a material and material perception using 3D–printed specimens rather than using complex, natural materials.

In computer graphics, the bidirectional reflectance distribution function (BRDF) is widely used to render photorealistic scenes. Similarly, we can define the force-induced displacement distribution function (FDDF), as a function of real variables that defines how displacement is produced by applied force to a tangible object [1][2]. The FDDF is an input-output relationship analogous with the BRDF, and can be measured from tangible objects using a calibrated force sensor and linear actuator. Once the FDDF is measured for a real object, we can estimate the haptic material perception (e.g., softness) based on a previous study in haptics. Once the FDDF is measured for a target object, in theory, we can reconstruct a shape with the target FDDF value using 3D printing technology. The simplest case is to reconstitute the force-displacement relationship of a tangible object.

This study aims at developing haptic materials using 3D printers for elucidating the mechanisms behind softness and texture material perception. For this purpose, we provide two examples of haptic materials as follows.

II. 3D–PRINTED HAPTIC MATERIALS

We decided to use OpenSCAD [3] to develop soft and textured materials. In the accompanying papers, we discuss how to quantify the softness and texture material perception of 3D–printed objects using the FDDF [1][2].

A. Parametric design of soft materials

For developing materials of different softness magnitudes, we adopted mechanical metamaterials to achieve different mechanical properties. Mechanical metamaterials contain a lattice structure (Fig. 1a). Lattice structure is repeated to construct the 3D models of mechanical metamaterial (Fig. 1b). We confirmed we could fabricate seventy-two materials in total using three 3D printers (Fig. 1c).

B. Parametric design of textured materials

We adopted canvas fabrics for developing textured materials. Canvas fabric is made with string of a certain diameter (Fig. 1d). By weaving strings of the same diameter, the roughness of the canvas fabric is defined (Fig. 1e). Based on this, we developed 3D–printed canvas textures (Fig 1f).

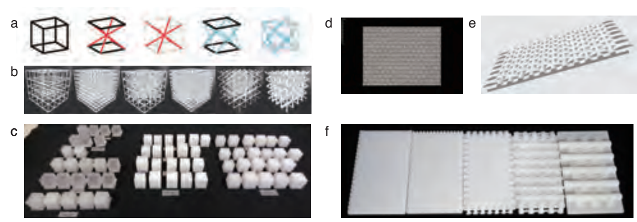

Fig. 1. Parametric design of soft materials (a, b) and textured materials (d, e). 3D Printed structures of different softness (c) and textures (f) are shown.

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[3] OpenSCAD. https://openscad.org/