A Demonstration of Metamaterial Textures

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Abstract
We present metamaterial textures—3D printed surface geometries that can perform a controlled transition between two or more textures. *Metamaterial textures* are integrated into 3D printed objects and allow designing how the object interacts with the environment and the user's tactile sense. Metamaterial textures offer full control over the transformation, such as in between states and sequence of actuation. This allows for integrating multiple textures that enable functional objects such as, e.g., a transformable door handle, which integrates tactile feedback for visually impaired users, or a shoe sole that transforms from flat to treaded to adapt to weather conditions.

In our hands-on demonstration, we show our 3D printed prototypes and several samples. Attendees can touch the objects and explore their different textured states.

Author Keywords
Metamaterials; textures; fabrication; 3D printing; programmable matter.

ACM Classification Keywords
H.5.m. [Information interfaces and presentation]: Misc.

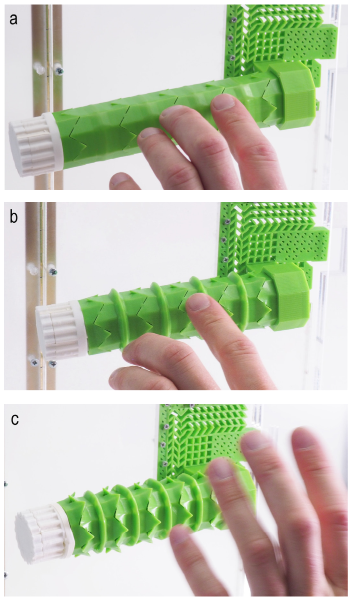

Figure 1: When an external force is applied, metamaterial textures undergo a controlled transformation. This door handle, for example, transforms (a) from flat (b) to rippled (c) to spiky, allowing the person behind the door to set a tactile message with three levels of *enter/busy/do not enter* messages for visually impaired or sighted users trying to enter.

Introduction

Digital fabrication machines such as 3D printers excel at producing arbitrary shapes, such as for decorative objects. Recently, researchers proposed going beyond designing merely the external shape, but to divide materials into many cells and to design each cell's structure to perform a specific deformation. Such structures are also known as *metamaterials*, which are "artificial structures with mechanical properties that are defined by their usually repetitive cell patterns, rather than the material they are made of" [4].

Researchers used the concept of metamaterials to design mechanical properties of materials, e.g., vary the stiffness across an object [6], to make materials contract in two dimensions when compressed in one dimension [5], or change the shape and surface of materials on a microscopic scale [1]. More recently, researchers in HCI applied the concept of metamaterials to create 3D printed objects that implement mechanisms [2] and simple computation [3].

In this work, we apply the main idea behind metamaterials, i.e., subdivision into a large number of cells and customization on a per-cell basis, to the *outsides* of 3D printed objects. The resulting *metamaterial textures* allow designers to shape how the object interacts with the environment and with the tactile sense of the user.

Metamaterial Textures

Metamaterial textures are 3D printed surface geometries that enhance objects by performing a controlled transition between two or *more* textures. Figure 1 shows an example. This door handle transforms from flat to rippled to spiky, allowing the person behind the door to set three levels of *enter/busy/do not enter* tactile messages for everyone trying to enter. As shown in Figure 2, the inside of the door handle consists of a grid of cells, which controls how the texture on the object's surface will be formed.

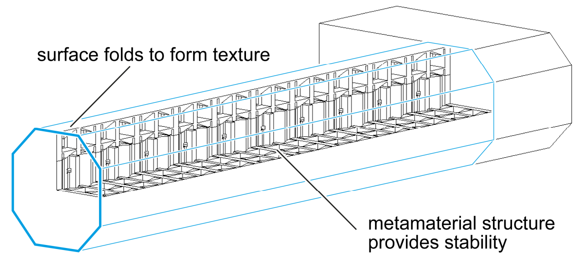

Figure 2: Metamaterial textures are made from cells that can fold upwards, creating a tactile bump. The metamaterial allows for this behavior while simultaneously providing stability.

Figure 3 illustrates the design of the underlying cells, which we call *fold cells*. Each cell implements a simple mechanism that transforms horizontal compression into vertical deformation, i.e., it *folds* upwards when compressed.

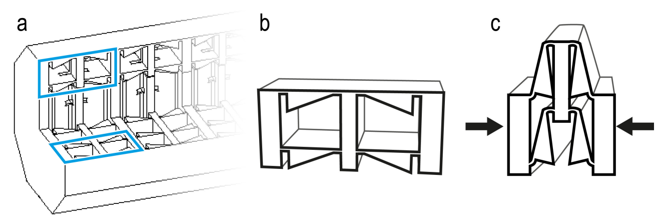

Figure 3: (a) Textured objects consist of many (b) unit cells, which (c) pop out of the object's surface, when compressed.

The cell consists of two four-bars, which is a basic linkage the rigid members of which move in parallel. When the cell is compressed horizontally it causes the four-bars to shear and the cell to fold upwards, creating a tactile bump. Hence, chaining multiple of these cells allows *popping out a texture* on the surface of the object. These four-bars can be repeated inside the object until it is filled.

Metamaterial textures are generally actuated to transition between textures by a global compression. To ease user interaction, we deploy them with a mechanism that allows producing the force required to deform the metamaterial texture. Figure 4 shows the mechanism we use to actuate the door handle texture in Figure 1. The mechanism runs strings through the door handle. As the user turns the knob, the strings are wound up and cause all fold cells to compress and to fold outward, forming the texture. During actuation metamaterial textures compress by a certain amount—30% in the case of the door handle example. This means our approach is limited to objects for which length is not a critical property.

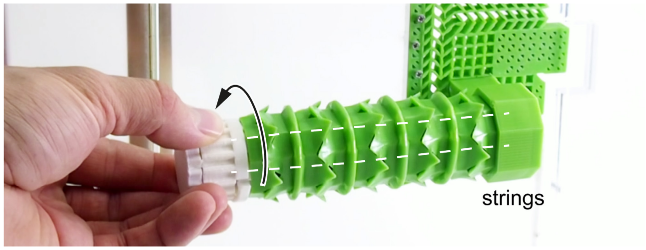

Figure 4: Users transition through the door handle's embedded textures by turning the knob. That winds up the strings on the inside, which compresses all cells and forms the textures.

Application examples

Metamaterial textures are suitable for conveying tactile messages or providing tactile feedback, for rapid prototyping of textured objects, or for adapting objects on demand.

1. Conveying tactile messages. Figure 1 showed an example for this category as a door handle that utilizes its surface to inform users (visually impaired or sighted) about one's availability for interruptions. We achieve three textures within this object by (1) alternating the two textures row-wise and (2) defining the sequence in which they pop out based on the amount of compression, i.e., compressing the door handle halfway only activates the smoother ridges, and compressing it all the way adds the spiky texture to the previous bumpy texture.

2. Adapting the functionality of an object to the context of use. Figure 5 shows a shoe sole with a metamaterial texture. It can be transformed from a flat sole to a corrugated one for more traction on snow or mud. This example illustrates one benefit of these metamaterial structures: they add enough *stability* to the origami-like surface to hold the weight of an adult (here 55 kg). To achieve this, we designed our cell to fold tightly, which prevents the beams from buckling in order to maximize strength (Figure 5c).

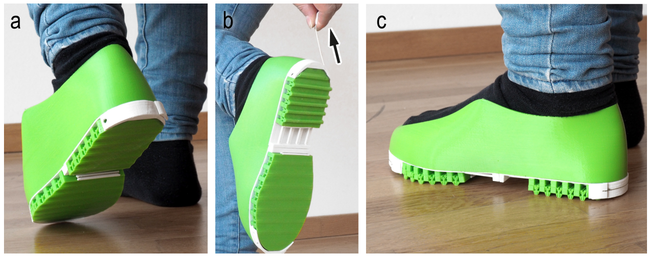

Figure 5: (a) This shoe sole is flat by default. (b) The user transforms it into a treaded sole it by pulling a string, e.g., when it starts snowing. (c) Note that the sole is functional and robust enough to walk on.

3. Exploring texture designs quickly. Metamaterial textures allow product designers to quickly iterate through multiple textures in one 3D print only, instead of fabricating many prototypes, which is slow. Metamaterial textures can be continuously actuated to different levels (Figure 6). This is useful when trying to explore how "strong" a texture should be during rapid prototyping. To test for the ergonomics of this bicycle grip, designers can prevent cells locally from folding by inserting spacers into the material that causes those cells to resist the compression to iteratively explore if the design feels right.

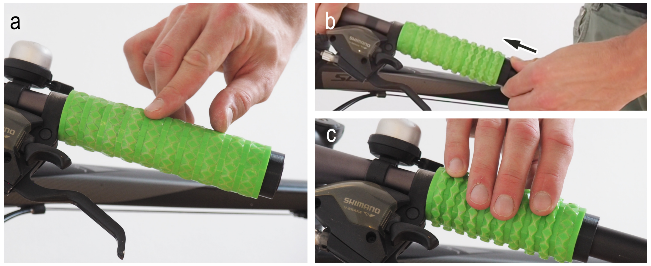

Figure 6: (a) Designers fabricate one single bicycle grip that they (b) actuate continuously to different levels, (c) to feel the tactile qualities during rapid prototyping.

Contributions and limitations

Our main contribution is the concept of embedding *multiple* dynamic textures into one 3D printed object using metamaterials. Such textured objects allow for continuously transitioning between magnitudes of the texture. Furthermore, they allow users to define the sequence in which the cells fold, which enables transitioning between multiple integrated textures after fabrication. On the contrary, our approach works only for objects in which exact dimensions are not critical.

While the resolution of our textures was dictated by our consumer-grade 3D printer (Ultimaker 2+), our parametric fold cells can be scaled down to produce hair or rough textures and could be fabricated using nano-scale 3D printers.

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