Coded Skeleton: Programmable bodies for shape changing user interfaces

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Figure 1: *Application example of Coded Skeleton. (a) Shape memory application. (b) Deformable skeleton. (c) Analyzed of a positive Gaussian curvature. (d) Actuated button.*

Abstract

We propose novel design method to fabricate user interfaces with mechanical metamaterial called Coded Skeleton. The Coded Skeleton is combination of shape memory alloys (SMA) and 3-D printed bodies, and it has computationally designed structure that is flexible in one deformation mode but is stiff in the other modes. This property helps to realize materials that automatically deform by a small and lightweight actuator such as SMA. Also it enables to sense user inputs with the resistance value of SMA. In this paper, we propose shape-changing user interfaces by integrating sensors and actuators as Coded Skeleton. The deformation and stiffness of this structure is computationally designed and also controllable. Further, we propose interactions and applications with user interfaces fabricated using our design method.

Keywords: Shape changing user interfaces, Metamaterials, Digital fabrication

Concepts: •**Human-centered computing** → **Interaction design process and methods;** *User interface design;*

1 Overview

1.1 Structures

A Coded Skeleton interface is a 3-D printed bodies with embedded actuator and sensor. The bodies parameters of the Coded Skeleton define flexibility and stiffness in a manner that it does not require complex composite construction. The Coded Skeleton consists of only a 3-D printed bodies, microcontroller, and SMAs. The SMAs functions as not only an actuator but also a sensor. We embedded the SMAs into the structure and used silicon tubes not to melt by SMA ' s heat (Figure 2 (a)).

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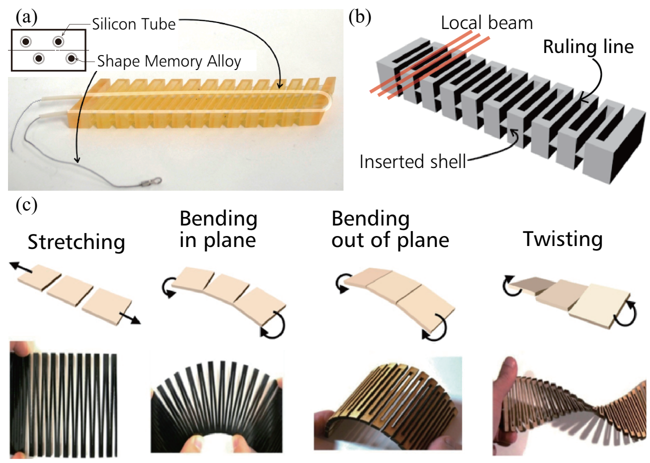

Figure 2: *(a) Coded Skeleton with shape memory alloys. (b) Coded skeleton. (c) Deformation modes in repetitive slit pattern.*

1.2 Printed bodies

The deformation shape of the Coded Skeleton is a developable strip, and its shape can be predefined with the required stiffness and flexibility. The proposed structure is an The deformation shape of the Coded Skeleton is a developable strip, and its shape can be predefined with the required stiffness and flexibility. The proposed structure is an improvement of repetitive slit pattern and is flexible in the designed deformation but is stiff in other deformations. We achieved this improvement by inserting a thin shell into the middle of this structure shown in Figure 2 (b), which prevents the structure from stretching, bending in plane, and twisting, thus preserving flexibility in out-of-plane bending (Figure 2 (c)). In addition, we propose Coded Skeletons on a surface, which deforms into nonzero Gaussian curvature surfaces such as dome or saddle surfaces (Figure 3 (b)(c)).

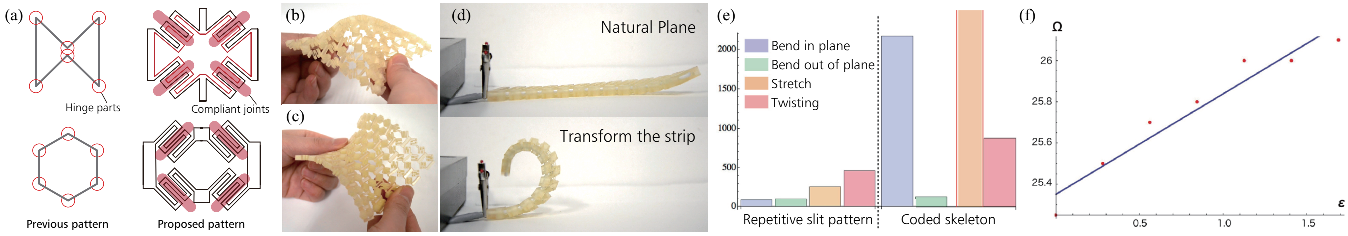

Figure 3: *(a) Applying compliant joint into hinge parts. (b) A Structure deforms negative Gaussian curvature. (c) A Structure deforms positive Gaussian curvature. (d) Actuation of Coded Skeleton. (e) Eigenmode and eigenvalue of coded skeleton. (f) Strain and resistance of Coded Skeleton.*

1.3 Deformation

Zero Gaussian curvature surface: To evaluate deformation property, we use eigenvalue analysis proposed by [Filipov et al. 2015]. Each eigenvector (eigenmode) represents a structural deformation mode, and its corresponding eigenvalue represents an excitation frequency that would result in the given deformation. The result demonstrated through Figure 3 (e) show the lowest eigenmode as a developable surface and the following eigenmodes are the Nth modes of the previous eigenmodes. The next eigenmode is twisting, however, its eigenvalue is relatively high, and thus twisting hardly occurs. Therefore, we considered the deformation shape of the Coded Skeleton as a developable strip (Figure 3 (e)). Furthermore, we can define the ruling line of the strip using directions of local beams (Figure 2 (b)). By using the pattern parameter proposed by [Taisuke Ohshima and Yamaguchi 2015], we can control the flexibility of the Coded Skeleton.

Nonzero Gaussian curvature surface: We constructed the structure with a Coded Skeleton to realize non developable deformations and to evaluate these structures through eigenvalue analysis. The key idea of this structure is convex and concave hexagon (Figure 3 (a)). These two structures have hinge in its vertices. A convex hexagon has a positive Poisson's ratio representing negative Gaussian curvature such as a saddle shape, and a convex hexagon has a negative Poisson's ratio representing positive Gaussian curvature. We applied compliant joints into hinge parts to make them function as hinges in Figure 3 (a) and its joints enable materials to have wide range of flexibility. Figure 3 (b)(c) shows out-of-plane deformation for the two structures. We analyzed these two structures by using "Inventor" provided by AUTODESK and used ABS resin for this analysis.

1.4 Analytical model

We propose an analytical model of deformation for a Coded Skeleton. We assume that it has only one deformation mode and its global deformation is large with an infinitesimal strain. The analytical model of the repetitive slit pattern and lamina emergent joints were proposed by [Taisuke Ohshima and Yamaguchi 2015] and [Delimont et al. 2015]. We modified this model considering our improvements. In order to enhance the stiffness preserving the flexibility in one mode, we inserted a thin shell into the repetitive slit pattern. Thus, we added stiffness term of the thin shell.

$$M = \left((a+b)GJ(a,b) + \frac{Ed^3}{24}\right)\phi$$

$\because J$ is torsion constant

ϕ is bending curnature

G is shear modulus

2 Actuator

The main idea for actuating a Coded Skeleton is to demonstrate geometric distance changes. The Coded Skeleton's strip has a finite thickness, and the length geometrically varies according to the deformation and distance from the neutral plane. We used this property to transform the strip with SMAs as shown in Figure 3 (d).

3 Sensor

SMAs can be used not only for actuators but also for sensors. Their resistance varies according to the strain and is almost proportional to strain (Figure 3 (f)).

4 Application

We propose 3 applications with user interfaces fabricated using a Coded Skeleton. First, we propose a shape memory application (Figure 1 (a)). A Coded Skeleton sense user inputs and changes stiffness and shape. Deformed shape keeps its state when it is powered on. This application indicates the Coded Skeleton has at least two shape state, initial state and deformed state. Programming shape memory between these two states are next challenge of our research.

Secondly, we propose a deformable skeleton (Figure 1 (b)). We embed the Coded Skeleton into plush doll. This structure has stiffness and predefined flexibility so that it works as bone and muscle both.

Finally, we propose an Actuated button (Figure 1 (d)). The Actuated button interface with Coded Skeletons on surface. Advantages of this application is its simplicity, flat shape embedded SMA deforms negative and positive surface so that it has inner space in deformed state and enable user to interact with.

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