Coded Skeleton: Programmable Deformation Behaviour for Shape Changing Interfaces

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

Keywords: Shape changing user interfaces, mechanical metamaterials, Digital fabrication

Concepts: **• Human-centered computing ~ Interaction design process and methods;** User Interface design;

1 Introductions

Soft and organic interfaces have been studied for soft robotics as alternatives for hard bodies toward real world oriented interaction. These interfaces are generally called programmable matter—controlling objects in the real world — and they are now a popular topic in computer graphics, display, and human-computer interaction communities. Various ideas and visions to organize and realize this concept have been proposed;– for example, programmable matter [Goldstein et al. 2005], radical atoms [Ishii et al. 2012], actuation interfaces [Poupyrev et al. 2007], and computational potential field [Ochiai et al. 2014]. These concepts focus on controlling real objects computational resorurces and generating physically programmable materials. These concepts will play very important roles in future interactive environments because they expand the range of computer applications from “painted bits” to the real world [Ishii et al. 1997]. To implement these conceptualizations, especially using soft materials for constructing, these interfaces are proposed using PneUI [Yao et al. 2013]. In this paper, we propose computational materials called mechanical metamaterials that exhibit unusual mechanical properties to integrate sensor and actuator kinematics. We present a metamaterial called Coded Skeleton for computationally integrated controllable shape changing interfaces.

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2 About Coded Skeleton

A Coded Skeleton interface is a 3-D printable structure with embedded actuator and sensor. The structural 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 printable structure, microcontroller, and shape memory alloy (SMA). The SMA functions as not only an actuator but also a sensor. The resistance of SMA varies according to its stretching. We embedded the SMA into the structure and used silicon tubes not to melt by SMA’s heat.

2.1 Material Properties of Coded Skeleton

The Coded Skeleton integrates sensor and actuator by computation. The deformation shape of the Coded Skeleton is a developable strip such as ribbon shape, 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. This property facilitates realizing a flexible and controllable actuator. We proposed two structures and this achieved this improvement by inserting a thin shell into the middle of this structure shown in Figure 2(a). One structure isolates bending out of plane and the other one isolates bending in plane. Here, “Isolate” means preserve flexibility in one deformation but make the structure stiff in the other deformations.

2.2 Deformation of the Coded Skeleton

The Coded Skeleton is flexible in one deformation, but stiff in the other deformations. To evaluate this property, we use eigenvalue analysis proposed by [Evgueni 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. A deformation mode with higher elastic energy requires a higher excitation frequency. This implies that the eigenvalue corresponds to the stiffness of the structure. The structure is analyzed with no boundary constraints, and thus, the first six eigenmodes correspond to the rigid body

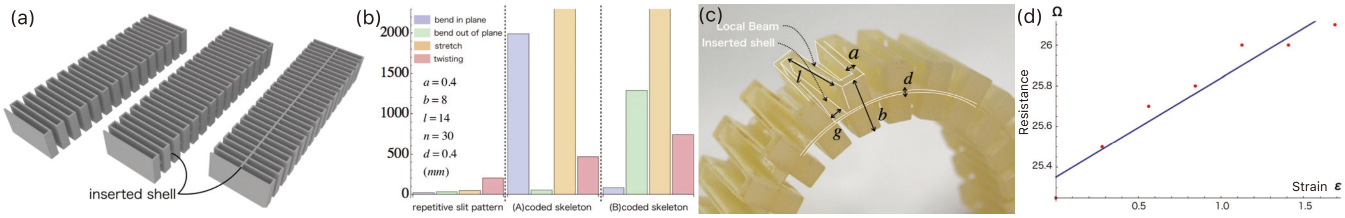

Figure 2: *(a) The structures of Coded Skeleton: repetitive slit pattern, (A)Coded Skeleton and (B) Coded skeleton. (b) Eigenmode and eigenvalue of Coded Skeleton. (c) Ruling line and structural parameters of Coded Skeleton. (d) Strain and resistance of coded skeleton*

motion of the structure in 3-D space. We omitted these modes in our experiments. The result demonstrated through Figure 2(b) show each of the lowest eigenmode as a desired deformation mode such as bending out of plane and bending in plane. Each of the next eigenmode is twisting, however, its eigenvalue is relatively high compared to lowest one so that possible deformation of Coded Skeleton is only desired one. Figure 2(b) are comparisons between repetitive slit pattern and two Coded Skeletons and *a, b, l, d* are structural parameters indicated figure 2(c). Here, *l* is a length of local beam, *d* is a thickness of instead shell, *a* is a width of local beam, *b* is a thickness of the structure and *n* indicates number of repetition of local beam in these structures. The one denoted (A) keeps flexibility about bending out of plane and the other one denoted (B) keeps flexibility about bending in plane. However, these structures stiffen the other deformations inserting thin shell. This result guarantee Coded Skeleton has only one deformation mode. We can define the ruling line of the strip using directions of local beams (Figure 2(c)). By using the pattern parameter proposed by [Ohshima et al. 2015], we can control the flexibility of the Coded Skeleton.

3 Actuator and Sensor of Coded Skeleton

Actuator and Sensor of Coded Skeleton is implemented with SMA. We referred to these functionalities in [Iwafune et al. 2016]. In this paper, we experimented output load of SMA and response speed of Coded Skeleton (Figure 3). This results indicates load of pulling not strong but it enough to move itself. Remaining problem here is simulation by solving upper equilibrium to determine deformed shape and predicting response speed.

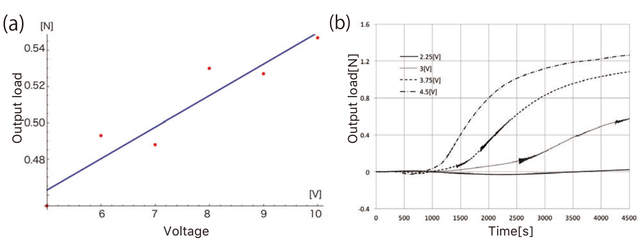

Figure 3: *(a)Output load of SMA varies according to applying voltage. (b)Response speed of Coded Skeleton varies according to applying voltage.*

4 SIGGRAPH ASIA Demonstration

At the SIGGRAPH ASIA 2016 Emerging Technology exhibition we demonstrate three applications.

Deformable skeleton: We embed Coded Skeleton into plush doll. This structure has stiffness and predefined flexibility so that it works as bone and muscle both. It has predefined flexibility in initial state to keep shape with flexibility and transforms designed shape. (Figure 1(b))

Shape memory application: We propose shape memory application. Coded Skeleton sense user inputs and changes stiffness and shape. Deformed shape keeps its state when it is powered on. This application indicates Coded Skeleton has at least two shape state, initial state and deformed state. (Figure 1(a))
Actuated button: Here we show button interface with Coded Skeletons on surface. Advantages of this application is its simplicity, flat sheep embedded SMA deforms negative and positive surface so that it has inner space in deformed state and enable user to interact with. (Figure 1(c))

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