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Designing a Passive Folding String Device with an Electromagnet

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Abstract

We propose a passively foldable string device. This string device is composed of multiple modules which have an electromagnet on each face. The string is folded according to the pattern of the magnetic poles of the electromagnets, like proteins that fold according to the order of amino acids. It is unfolded if all the magnets have the same polarity. This string can be folded even if the string is long and heavy using an external force, for example a vibration or convection. This kind of device can be used not only as an experimental tool for studying a self-folding process but also as a three-dimensional physical display. In this paper, we propose a design of the folding string device and show some results of experiment for verification of this idea.

Introduction

Self-assembly is a process where some components autonomously organize into structure or pattern without an external direction. This process is ubiquitous in nature, especially in living system. For example, a protein is folded autonomously from a polypeptide according to the arrangement of amino acids constitute the polypeptide.

These kinds of process might be exploited to built an artificial system with the characteristics of scalability, reversibility, self-repairing or adaptability. There are many researches about artificial self-assembly systems from nano scale to *cm* scale [Whitesides and Grzybowski, (2002)] and a few research among them focus on self-folding [Cheung et al, 2011], [Knaian et al. (2012)], [Hawkes et al. (2010)]. Such kind of self-assembly processes are considered to be useful for constructing more complex and smaller object efficiently at nano-scale. Even at *cm* scale, for example, it is useful for manufacturing in an extreme environment such as space or deep-sea, or three-dimensional physical display. In this research, we focus on a self-folding system at *cm* scale.

In prior work, Cheung et al. (2011) proposed a string robot which is composed of modular robots and can fold into an arbitrary three-dimensional shape with their method which can generate Hamiltonian path from any given graph and Knaian et al. (2012) developed a small stepper motor and applied it to a string robot. However, these folding robots can be folded by only their motor power, thus the longer and heavier the string becomes, the more difficult a folding is.

We develop a passively foldable string device using electromagnets, which can be folded not only actively but also passively even if the string is long and heavy. In this system, the resulting shape emerges via an interaction of magnetic forces much like amino acids that are attracted and repelled from each other in real proteins. Thus, this device can be used not only as physical three-dimensional display that can construct three-dimensional shape but also as an experimental tool for studying self-folding process. In this paper, we propose a design of passive folding string device and show its prototype.

Design

In this section, we describe the design of a passively foldable string device. The modules are shaped like right-angled tetrahedron (Figure 1a). A string composed of such a tetrahedron-shaped module can fold into an arbitrary three-dimensional shape and unfolded into a straight line [Griffith. (2004)]. Each module has an electromagnet on each face. These modules are connected by hinge joint (Figure 1b). Thus this string is folded according to the arrangement of the magnetic poles of the electromagnets and if all the magnets have the same polarity, the string is unfolded. For controlling a magnetic pole and a magnetic force of the electromagnets, wireless or wired communication between each module and computer are needed.

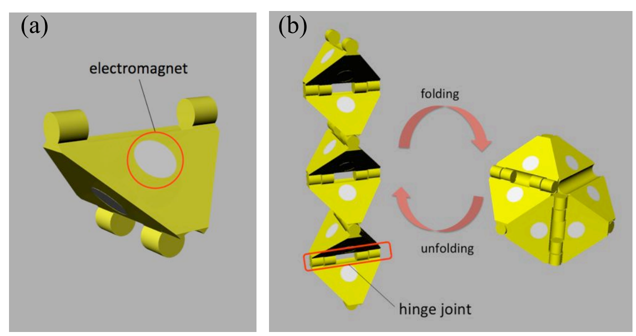

Figure 1: Design of string device. (a) Single module. The module has an electromagnet on each face. (b) String and folded object. The string is composed of multiple modules by hinge joint. The string is folded into and unfolded from three-dimensional object. The string of six modules in the left and an octahedron folded from the string on the right of the figure.

If another permanent magnet is put on each face, the structure, which is folded from a string, can be maintained even if the power supply to electromagnet is cut off (Figure 2). In this case, the force of the electromagnet must be stronger than the force of the permanent magnet.

As described above, the folding robot in prior works use motor actuation for a folding, thus the folding of long and heavy string is difficult. The string device we propose use no motor actuation but electromagnet, and is expected to use external forces in the case of longer string. Therefore, even if the string is long and heavy, a folding can be supported by an external force easily, for example a random vibration to container where the string is or a random convection if the string is underwater.

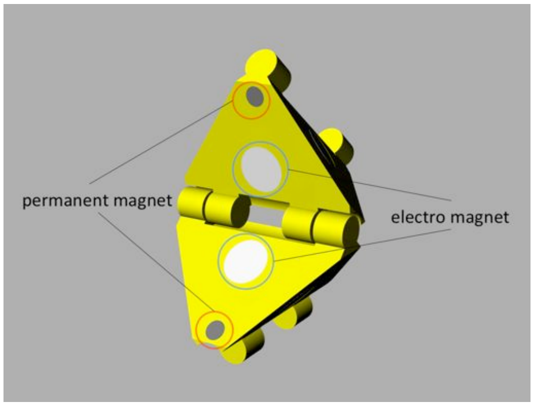

Figure 2: Distribution of electromagnets and permanent magnets on the faces of the modules for maintaining a folded shape.

Implementation

In this section, we show a first prototype of string device. We implemented the prototype for verification of the idea of passively foldable string device. The prototype is composed of three modules, which has no electromagnet but a permanent magnet on their each side (Figure 3). Except for using permanent magnet, the design is the same as described above.

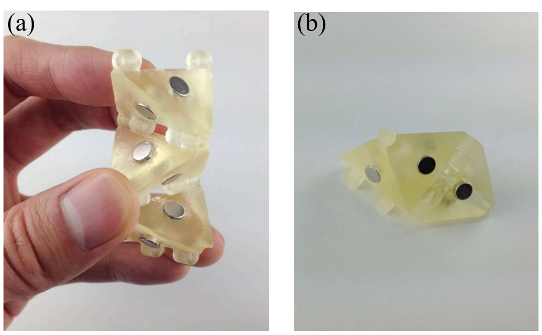

Figure 3: Prototype of string device. Each module was printed by 3D printer (Objet Eden260) and has a permanent magnet on each face. (a) Initial configuration. (b) Folded object.

We conducted a small verification experiment using this prototype composed of three modules. We tested whether the prototype can fold correctly in cases of two kind of magnet; strong (neodym, $\phi\, 6 \times 3$mm) and weak (neodym, $\phi\, 3 \times 1.5$mm). As the results, in the case of strong magnet, the string could be folded successfully from an initial line-liked configuration without help from an external force. On the other hand, in the case of weak magnet, it was folded successfully only in case of applying an external vibration to a container where the string was (Figure 4).

Figure 4: Passive folding with external force. The string, which is composed of three modules that have weak magnet, cannot fold by itself, but with external force it can be folded.

Discussion

In this paper, we proposed a design for a new type of passive string device and showed its first prototype. The results of verification experiments with a prototype showed that this passively folding mechanism using magnet with an external force could be effective.

This kind of robotic device can be folded into arbitrary three-dimensional shapes and also transformed from one shape to other shapes repeatedly via folding and unfolding process. Therefore, it might be used as a three-dimensional physical display, by which we cannot just watch a three-dimensional object but also touch or use it. It can also be used as an experimental tool for studying self-folding process.

In future work, we implement the string device completely using electromagnets. For this kind of folding string device, the order of folding is important, because if the order is not correct, the string is tangled and fails to fold. Therefore we also need to study the methods for generating an optimized order of folding. We also conduct some experiment using this device, for example, whether the same arrangement of magnetic pattern can be folded into the same structure or different structures.

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