Variable Stiffness Shape-changing Interface using Artificial Muscle

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Abstract: In this paper, we explore the implementation of variable stiffness for shape-changing interface applications. We proposed a stiffness control mechanism using a combination of Pneumatic Artificial Muscle(PAMs) and 3D-printed reinforcement. The three reinforcements include a locking module, a plastic deformation module, and a rotational brake module. We demonstrate the feasibility of this mechanism through five application examples and conclude with a discussion.

1. Introduction

Variable stiffness is a beneficial feature for a computer interface because it can exponentially increase the interaction and utilization possibility. In previous work on soft robotic applications, a gripper that can grasp various objects by changing the gripper stiffness has been proposed [1]. It shows how the interface can adapt to both environment and the target object effectively, with little control and energy cost. Although previous works have proposed some applications of variable stiffness for computer interface[2], [3], the capabilities of both shape and stiffness change simultaneously have yet to be fully explored. In this paper, we develop a shape-changing interface with variable stiffness capabilities. We utilize Pneumatic Artificial Muscle(PAMs) as actuators and 3D printed reinforcement to alter the actuation force into shape and stiffness change. Employing these features, we introduce five shape-changing interfaces application.

2. Related Work

The common technique of variable stiffness is the vacuum jamming technique which includes granular, layer, and fiber jamming [2], [3], [4]. These stiffness control techniques are able to exert a high degree of stiffness change. However, it is not easy to combine the shape-changing actuation with the jamming mechanism due to the complexity of multiple actuator control [5]. In this paper, we proposed a convenient control system, where both shape deformation and variable stiffness actuation are combined in one mechanism.

Deployability is a useful feature for the shape-changing interface. Some advantages of the deployable interface are the storing easiness, increased change in durability, and adaptability to various environments. Previous work has proposed a soft robot that can be deployed for rescue purposes[6]. NinjaTrack and PuPoP[7], [8] are user interfaces that can be deployed by the user at will or through some interaction. Poimo [9] is a mobility device that can be collapsed to be stored easily.

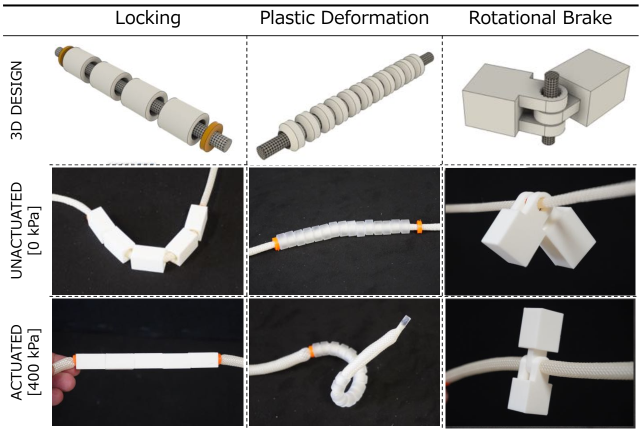

Fig. 1 Variable stiffness behavior related with reinforcement modules

3. Design and Implementation

We design three types of reinforcement including locking, plastic deformation, and rotational brake. Variable stiffness is achieved by altering both the contraction force and expansion force of the PAMS.

(1) **Locking module** is based on the beaded jamming phenomenon. We use the contraction force of PAMs to tension an array of hollow modules, and interlock them to each other.

(2) **Plastic deformation module** has unique behavior which allows the structure to retain its shape after being bent by an external force.

(3) **Rotational brake module** is based on a hinge structure with PAMs as its shaft. When PAMs is unactuated,

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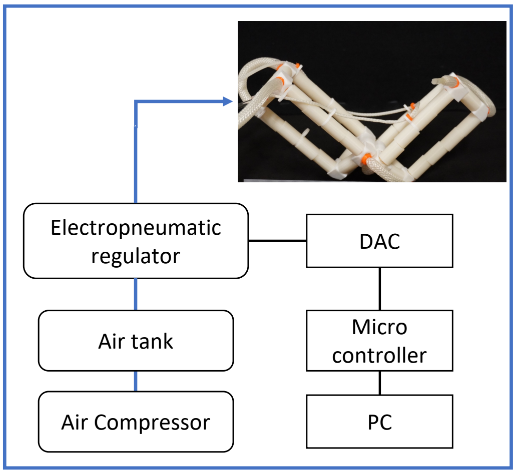

Fig. 2 Pneumatic control diagram

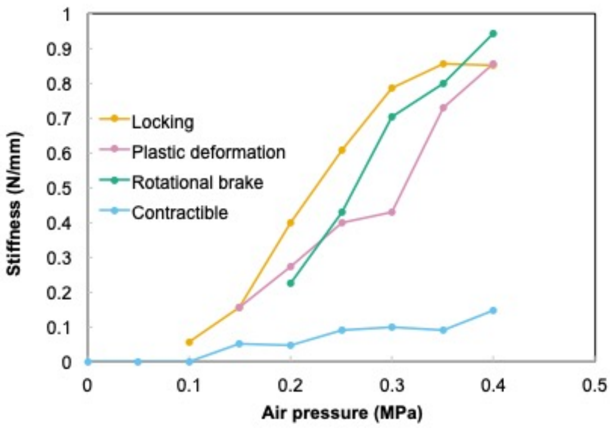

Fig. 3 Air pressure and stiffness control relationship

the hinge can rotate freely. However, when PAMs are expanded inside the hinge, they will rub together and resist rotation.

3.1 Fabrication

Our proposed system only consists of 3 parts: pneumatic artificial muscles(PAMs) as actuators, 3D printed structures as reinforcement, and compressed-air controls. To fabricate reinforcement structures, users can use both FDM and SLA 3D printers. The material used mostly rigid filaments such as PLA and ABS, however for bending modules, we use flexible filament TPU95. After 3D printing, the user assembles the reinforcement similar to beads craftworks. Here manual work of threading PAMs through holes in reinforcements is needed.

3.2 Control

Both the deformation state and stiffness level is controlled by air pressure. The air pressure controlled by the electropneumatic regulator ranged from 0 0.4 MPa. We conduct a technical evaluation to investigate the relationship between stiffness change and air pressure. Figure 3 shows the stiffness control range for each module.

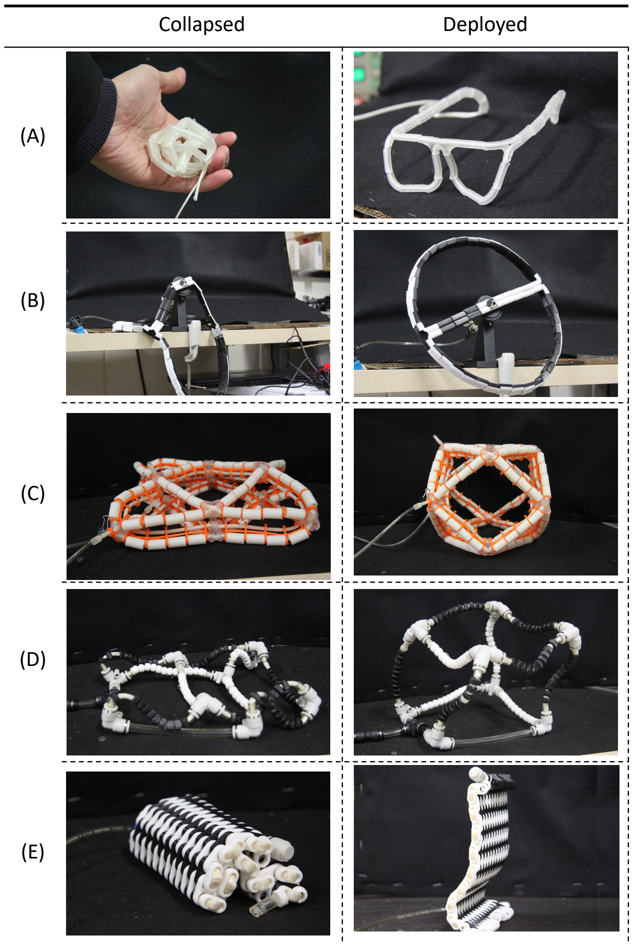

Fig. 4 (A) Crumbled device, (B) Incapacitate device, (C) Flaten device, (D) Deformable device, (E) Fabric-like device

4. Application

Here, we demonstrate the application of variable stiffness features on shape-changing interfaces.

4.1 Crumbled device

Figure 4(A) shows glasses that can be softened into a totally flexible state. In this state, the device can be crumbled without breaking and easily stored inside a small pocket. When actuated, it instantly returned to a normal glasses shape.

4.2 Incapacitate device

Figure 4(B) shows a steering-wheel concept that can detect when a thief tries to steal the car. In that case, the device can incapacitate by collapsing the structure, making the thief unable to control the wheel.

4.3 Flaten device

Figure 4(C) shows a vector equilibrium structure that can be flattened when unactuated. In a flattened state, it can go through narrow space. When deployed, the structure can carry a pratical load of up to 2kg.

4.4 Deformable device

Figure 4(D) shows a cube structure that consists of the plastic deformation module. When actuated, at first it will construct a cube structure. Additionally, the shape can be deformed by the user freely due to the shape-retaining capabilities.

4.5 Fabric-like device

Figure 4(E) shows a fabric-like device that consists of rotational brake modules in a grid structure. The device is soft and flexible in the normal state, and malleable when actuated. It can be utilized for wearable devices such as medical casts where users can easily stiffen or soften it to be easily removed.

5. Discussion

In this paper, we did not implement sensors for interaction. However, the already installed air-pressure sensors and additional sensors such as acoustic, optical, and contact sensors can be utilized. The sensor can be inserted into the 3D printed substrate or embedded into the PAMs filament.

Currently, we only implement small-size devices with dimensions of up to 300 x 300 mm. In the future, room-size structures with deployability functions can be implemented. However, a computer simulation to calculate the optimized truss frame, load endurance, and shape deformation will be needed first.

Although our system is not suitable for practical application due to the pneumatic device shortcoming, where it needs a heavyweight compressor and power source. We believe that this technology problem will be resolved in the near future. In this stage, our vision is to explore the new possible application, as it will motivate progress in core technology such as materials, actuation, sensing, and energy.

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