Demonstration of Springlets: Expressive, Flexible and Silent On-Skin Tactile Interfaces

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ABSTRACT

We present *Springlets*, expressive, non-vibrating mechanotactile interfaces on the skin. Embedded with shape memory alloy springs, we implement Springlets as thin and flexible stickers to be worn on various body locations, thanks to their silent operation even on the neck and head. We present a technically simple and rapid technique for fabricating a wide range of Springlet interfaces. We developed six modular Springlets: a pincher, a directional stretcher, a presser, a puller, a dragger, and an expander (Fig. 1). In our hands-on demonstration, we show our modular Springlets and several Springlet interfaces for tactile social communication, physical guidance, health interfaces, navigation, and virtual reality gaming. Attendees can wear the interfaces and explore their expressive variable force profiles and spatiotemporal patterns.

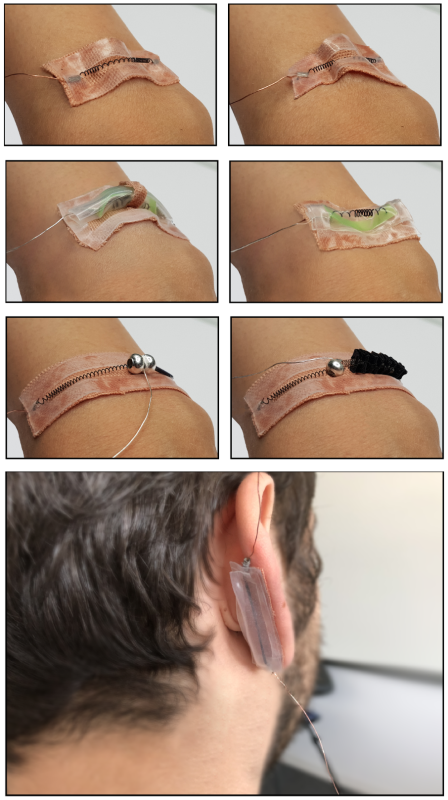

Figure 1: Springlets on-skin stickers enable expressive mechanotactile output on the user's skin. They use shape memory alloy springs to achieve a thin, flexible, and silent form factor that can be worn on challenging body locations, including the neck and head region. They are easy to fabricate and customize for various body locations and tactile patterns using accessible materials and DIY tools.

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KEYWORDS

Tactile Display; Shape Memory Alloys; Shape-Changing; Fabrication; On-Body Interaction; Wearables

INTRODUCTION

Tactile perception on our skin is inherently multimodal. In recent years, researchers explored non-vibrating mechanotactile output like tapping, dragging, twisting, and squeezing as a more natural and more expressive alternative to vibration on the skin [3]. So far, however, moving beyond vibrotactile output has required bulky, rigid, and noisy electromechanical actuators, such as motors, servos, and pumps [2]. The resulting tactile displays tend to be cumbersome to wear, scale, and distribute across the body without limiting natural movement, and cannot be placed near the head or neck due to their noise [1]. In addition, each type of mechanotactile output typically requires its own custom mechanical actuators and construction, making these systems hard to make and combine. In this work, we describe the actuation mechanism and fabrication of *Springlets*, a novel class of skin-worn interfaces that generate expressive, non-vibrating, silent mechanotactile output. Our approach embeds a single type of soft actuators, *shape memory alloy (SMA)* springs, in ergonomic stickers that can be worn across the body without restricting the users.

SPRINGLETS

Our approach is based on using a soft SMA spring to stretch the skin where an interface is attached, or move an object on the skin surface between two attachment points. The basic idea of using an SMA spring as a mechanotactile actuator is illustrated in Fig. 2.a: When current flows through the SMA spring, it heats it up, contracts and reduces its effective length, stretching the skin at the attachment points towards its center, simulating a pinch gesture. But depending on how the spring is attached to the skin, a wide range of touch sensations can be produced. The contraction stops when the spring reaches its shortest length, or when the *bias force*, here the skin elastic resistance, becomes higher than the spring's contraction force. Once power is removed, the bias force stretches the SMA spring back to its original position. We identify two types of Springlet actuators:

Skin actuators attach the ends of the SMA spring to the skin and apply the contraction force directly at the attachment points. In these actuators, skin elastic resistance serves as the main bias force. In Fig. 2.a, an SMA spring stretches the skin at the attachment points symmetrically, creating a pinch. In Fig. 2.b, an SMA spring stretches the skin at the attachment points asymmetrically, due to unbalanced bias forces, creating a directional stretch.

End-effector actuators attach at least one end of the SMA spring to an *end-effector* and apply the contraction force directly to it. An end-effector may be a rigid or a soft object that is attached to the SMA. In these actuators, a soft end-effector or a bias spring reverts the SMA to its original position after contraction. In Fig. 2.c-d, an SMA connected to a soft bendable object bends the object, causing

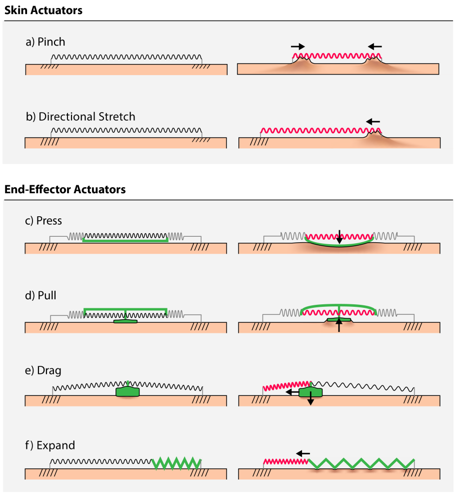

Figure 2: Springlets' actuation mechanism. Skin actuators deform the skin by applying force directly to the attachment points. End-effector actuators move or transform objects on the skin surface.

it to press or pull the underlying skin. In Fig. 2.e, two SMA springs connected to a rigid object pull the object alternately, causing it to drag over the skin surface in two directions. In Fig. 2.f, an SMA spring connected to a soft zigzag object pulls the object, causing it to unfold and expand on the skin.

Fabrication

A Springlet sticker is composed of three functional layers (Fig. 3):

Layer 1: The enclosing layer covers the embedded SMA from one side to protect it and the user from accidental contact. The layer leaves a 2 mm spacing between it and the SMA, which is embedded in *layer 2: the tactile layer*, to allow for free and frictionless movement. This air gap also serves to insulate the heat of a contracting SMA. The layer may also include a ventilation mechanism e.g., holes in its surface, to accelerate SMA cooling. This layer is cut in the shape of the tactile layer from a thin sheet of self-adhesive silicone-rubber tape.

Layer 2: The tactile layer is a frame that embeds the SMA spring and end-effectors and provides a custom design for the skin attachment points. The layer's design and contact points with the SMA determine the shape of movement and distribution of force on the skin. The opening at the center of this layer frames the tactile interaction area on the skin. It provides movement space for the SMA to contract and expand. For end-effector actuators, the opening is necessary to sense the movement of the end-effector on the skin. This layer can be customized and scaled to embed several SMAs and end-effectors and create tactile displays for various applications and body locations. This layer, like layer 1, is made of a thin sheet of the silicone-rubber tape. Incisions in this layer are made to thread the SMA spring and secure it at the contact points.

Layer 3: The attachment layer encloses the SMA from the other side of the sticker, and it is used to attach a Springlet on the skin or other surfaces. For this layer we used kinesiology, a breathable medical fabric tape that is thin, stretchable, and can withstand the heat of a contracted SMA. For additional safety, we line this layer with a piece of thin thermal insulating tape.

APPLICATIONS

We present five unique applications that demonstrate how Springlets can be customized, scaled, and digitally-controlled to create expressive tactile effects across the body, see Figure 4.

(a) Intimate Messenger on the Ear: Springlets' noiselessness is one of the major advantages in this scenario. We attached a skin actuator Springlet between the helix and earlobe of the ear, and since the earlobe is softer, our Springlet behaved like a stretcher, pulling only on the earlobe with three levels of stretch. With this interface, it is possible for the user to receive basic haptic messages that convey feelings or intentions.

(b) Non-Restricitive Motion Guide on the Forearm: Most motion guidance systems for the limbs are kinesthetic and restrictive in nature. The stick-on and pliable features of Springlets enable

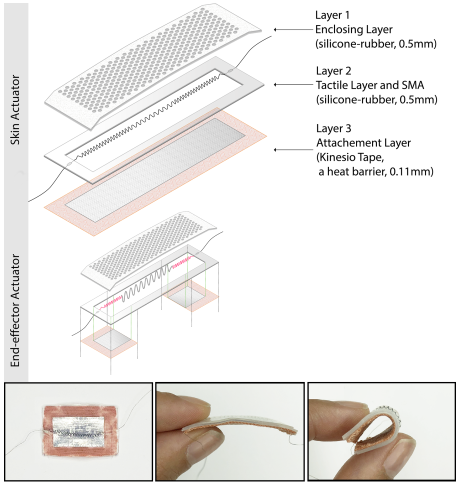

Figure 3: Springlets' multi-layer sticker structure. Bottom: Demonstration of a 3.5 mm thick Springlet embedding a 0.62 mm diameter SMA spring and lined with a heat barrier.

Springlets' Controller

We use a wireless controller with pulse-width-modulator (PWM) pins to control the current flow, a RedBear BLE Nano with a ULN2803A motor controller, to supply a current of 500mA from a 9 V battery. Each SMA connects via a thin wire between a pin on the motor controller and ground.

placing them freely on the body and grounding them directly on the skin, without restricting its natural movement. Our interface is composed of two stretch Springlets embedded with large SMAs that can generate a wide range of forces. The Springlets are placed on the outer and inner sides of the forearm and can be actuated in sync for a larger impact, or separately to deliver different hints.

(c) Breathing Coordinator on the Chest: We developed a breathing coordinator that mimics the natural expansion and contraction of the chest while breathing. The interface is composed of two expander Springlets connected back-to-back on the chest. To signify 'inhale', the SMAs contract in sync, causing the zigzag end-effector to expand on the skin gradually. When the springs start to expand back, the zigzag starts to contract to its original position, signifying 'exhale'. By controlling the amount and duration of the driving current we can mimic different breathing rhythms.

(d) Navigator on the Back: We implemented a haptic navigation device that can be worn on the back. Our interface uses four stretch Springlets that are mapped to the 'forward', 'backward', 'left', and 'right' directions. The stimuli of the stretchers are spaced 5–8 cm from each other to guarantee a clear two-point discrimination. More directions could be signaled by combining two or more stretchers.

(e) Virtual Reality Backpack: We present an application that maps virtual weights in a player's backpack to dynamic pressure on his shoulder. Mounting three pressure Springlets on the shoulders of a user enables sensation of increasing weight in the place where backpack straps would tug. Collecting items generates short bursts of pressure to simulate throwing them into the backpack, while the basic pressure used for these bursts rises with the fill level of the user's inventory.

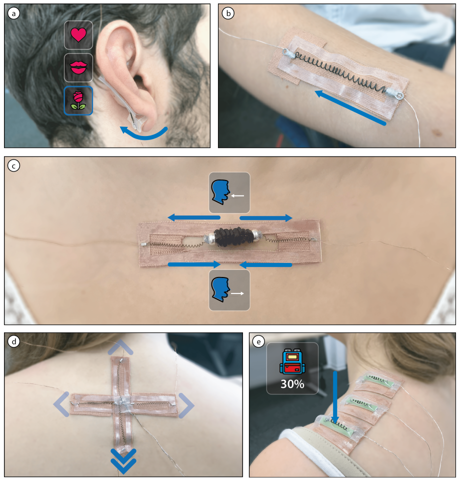

Figure 4: Springlets' interactive applications. (a) Intimate messenger, (b) Non-restrictive motion guide, (c) Breathing coordinator, (d) Navigator, (e) Virtual reality backpack.

CONTRIBUTIONS

Our main contribution is the concept of Springlets, a novel class of SMA-based tactile interfaces for expressive, non-vibrotactile output in soft and discreet form factors that can be worn like stickers. We describe a technically simple and rapid technique for fabricating Springlet interfaces using a single type of actuator. In future work, we'll investigate feedback systems to improve the control, resolution, and bandwidth of Springlets.

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