Design and Analysis of a Pneumatic 2-DoF Soft Haptic Device for Shear Display

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***Abstract*— Haptic devices use touch to enable communication in a salient and private manner. While most haptic devices are held or worn at the hand, there is recent interest in developing wearable haptic devices for the arms. This frees the hands for manipulation tasks, but creates challenges for wearability. One approach is to use pneumatically driven soft haptic devices that, compared to rigid devices, can be more readily worn due to their flexibility and light weight. We propose a 2-DoF soft wearable tactor that can be worn on the forearm and provides shear forces. The tactor is comprised of four soft fiber-constrained linear pneumatic actuators connected to a dome-shaped tactor head. The tactor can provide fast, repeatable forces on the order of 1 N in shear, in various directions in the plane. The tactor can be attached to a flexible housing and worn on the arm. A user study demonstrated the performance of the device in providing directional cues, highlighting the challenges of grounding soft wearable devices and the limits of perception on the human forearm.**

I. Motivation

Haptics – the sense of touch – enables humans to perform a wide variety of exploration and manipulation tasks in the real world. In virtual worlds and robot teleoperation scenarios, this sense of touch must be artificially recreated by stimulating the human body in a manner that produces the salient features of touch needed to enhance realism and improve human performance. Wearable haptic devices are becoming increasingly popular as a means to improve human experiences in virtual environments. In addition to applications in virtual environments, wearable haptic devices could facilitate and enhance communication between humans and robots, humans and virtual agents, and humans and humans.

Approaches from soft robotics are now being used to create wearable haptic devices that are safe, light weight, and provide a comfortable user experience. In this paper, we present a new 2-degree-of-freedom (2-DoF) pneumatic soft wearable haptic device that is mounted on and provides stimulus in the form of skin stretch to the forearm, as shown in Figure 1. Each single soft tactor is light weight and easily fabricated. The device can provide skin stretch in different directions in the plane of the arm. A user study with 10 participants indicates that four different direction cues can be distinguished at a rate better than chance, and that grounding challenges and perceptual limits of the human forearm constrain performance.

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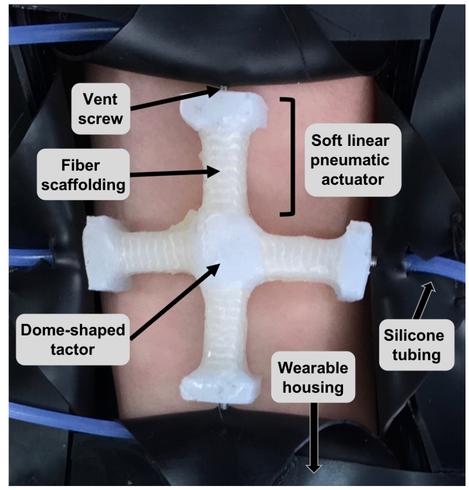

Fig. 1. A 2-DoF soft haptic device is comprised of four fiber-constrained linear pneumatic actuators connected to a dome-shaped tactor head, and attached to a wearable housing.

II. Prior Work

Many wearable haptic devices have focused on stimulating the skin on the palms of the hands and fingertips because it is glabrous (non-hairy) skin; glabrous skin has higher sensitivity than hairy skin because it has more mechanoreceptors. However, most haptic devices mounted on the fingertips and hands inherently impede manual interactions with the user's environment. Instead, our device delivers feedback to the forearm, leaving the hands free to perform other manipulation tasks.

Wearable tactile devices on the forearm have been demonstrated to provide cues such as vibration and normal skin deformation [1], [2], [3]. Both direction cues and learned vocabularies of tactile cues can be transmitted via forearm mounted devices [4], [5]. Bark et al. found that using shear forces on the arm provides superior and more intuitive directional feedback than vibrotactile feedback [6]. Biggs et al. showed that mechanoreceptors on the forearm are more sensitive to tangential forces than normal forces [7].

Skin stretch has been used to create convincing illusions on the fingertips by providing shear forces to the skin on the fingertips. Literature has shown that shear can enable various tasks in virtual environments, such as mass perception [8], stiffness perception [9], and path-following [10]. However, we are aware of only two published results on haptic devices that provide shear forces to the forearm: a fabric device that caresses the arm by applying shear forces [11] and the Haptic Rocker, which conveys learned haptic cues [12].

There is significant research activity toward understanding the underlying mechanisms of perception skin stretch. Work by Pare et al. examined perceived magnitudes of shear forces from 0.15 to 0.7 N, and found that human perception of tangential force scales with the magnitude of the normal force applied [13]. A set of unpublished pilot studies performed our research group with a Phantom Premium haptic device found that 0.23 N of shear force is clearly perceivable when applied to the forearm (n = 17), and that just 1 mm of skin displacement at the forearm allows participants to identify the direction of a shear stimulus with an average error of 30 degrees. Based on these previous studies, the soft haptic device created for this work was designed to provide a shear force between 0.5 and 1 N and have displacements of 1 to 5 mm, depending on the stiffness of the skin.

The main contribution of this work is a novel 2-DoF wearable pneumatic device that utilizes skin stretch, a promising and highly intuitive means of directional haptic feedback, while taking advantage of unused skin "real estate" on the forearm. Here, the synergy of soft robotics and haptics gives rise to a multi-degree-of-freedom device that provides wearable haptic communication.

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