

Dielectric Elastomer Actuators for A Portable Force Feedback Device

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Abstract. This paper focuses on the development of novel actuators for a portable force feedback glove for, but not limited to, the simulation of organ palpations. A conceptual design of a chain-like actuator based on electroactive polymers is introduced. One elementary actuator of this chain was built in order to explore and optimize the actuator manufacturing process. Actuators manufactured with this stable process were characterized through isometric and isotonic measurements. The results show that dielectric elastomer actuators are promising for a portable force feedback device.

1 Introduction

We found that among all diverse open surgeries there is one common activity, which is the palpation of organs with the hand. Surgeons use their hands in around 20% of the operation time to expose, to feel or to determine pathological changes of the organ. Therefore, it is important for medical students for instance to gain experiences in haptic sensations during their quite short education period.

Nowadays, some haptic simulators have been integrated into visceral surgery simulations. They feed sufficient touch sensations back to the surgeons, helping them to better control the robotic end-effectors. Unfortunately, these simulators are only limited to specific tasks with certain instruments [1, 4]. A glove-like force feedback device provides a possibility to simulate palpation. It has either local actuators on the glove [5], or has a cable-driven exoskeleton structure with remote actuators [6]. Both force feedback gloves enable the user to feel rigid virtual objects without weight. However, the on-hand located actuators or the bulky structures over the hand restrict the motions of surgeon's hands. In order to develop a powerful, lightweight and non-obstructive haptic interface, we studied the physical principles that generate forces and new actuation technologies. We have found that the dielectric elastomer technology shows a better overall performance than other technologies [7, 8].

Dielectric elastomer actuators, a subgroup of electroactive polymer actuators, can change their shapes when subjected to an electric field. They are lightweight, have a high strain response (215%, [8]) and a short response time; In addition, they can be tailored to fit different applications. Therefore, dielectric elastomer actuators are attractive for applications such as biomimetics and robotics [9, 11].

In this paper we discuss the development of dielectric elastomer actuators for glove-like force feedback devices. We first describe the requirements on actuators, then a conceptual design of a chain-like actuator and a stable manufacturing process of an elementary actuator. We then present measurements and results. In the end we conclude and discuss the work.

2 Requirements

In order to compare different actuation technologies as well as to get the prerequisites for a proper actuator design, it is necessary to understand the haptic-related issues during organ palpations and the human haptic system [7]. Table 1 summarizes typical characteristics of the human hand required for a palpation simulation (typical values for other tasks are added in brackets).

The actuator has to generate forces with a human perceptual bandwidth when imposing forces on the user's fingertip. If the operator does not touch a virtual object, the actuator shall follow the voluntary motion of the finger without impeding it. The elongation is taken as a relative length change of a tendon starting from the wrist to the fingertip, when the middle finger bends from the stretched position to the fist.

Requirements	Palpation haptic simulation (Human haptic system)
Min. sensing pressure	0.2 N/cm^2
Max. force exertion of the fingers	5 N (30-40 N)
Sustained force exertion (15% of the max. force exertion)	0-5 N (4.5-7 N)
Force control bandwidth of the fingers	1-30 Hz
Perceptual bandwidth	10-320 Hz (10-1000 Hz)
Max. elongation	8%

Table 1. Requirements on actuators for force feedback gloves [12, 15].

3 Conceptual design of an actuator based on dielectric elastomers

3.1 Dielectric elastomer actuators

The working principle of a dielectric elastomer actuator is shown in Figure 1. Such an actuator is basically a compliant capacitor, where a thin (μm) elastomer

film is sandwiched between two compliant electrodes. When a high DC voltage (kV) is applied to the electrodes, the arising electrostatic force squeezes the elastomer film in thickness and thus the film expands in planar directions. When the voltage is switched off, the compliant capacitor returns to its original shape.

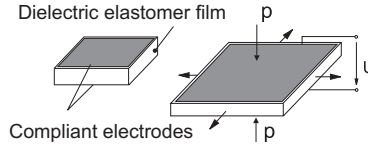


Fig. 1. Working principle of a dielectric elastomer actuator.

Assuming that the volume of the film remains constant, the effective pressure [9] is

$$p = \epsilon_r \epsilon_0 \frac{U^2}{d^2} \quad (1)$$

where ϵ_r is the relative permittivity of the elastomer, $\epsilon_0 = 8.854 \cdot 10^{-12} \text{As/Vm}$ is the free space permittivity, U is the applied voltage and d is the thickness of the elastomer film. The pressure increases quadratically with the electric field.

3.2 Conceptual design of the chain-like actuator

Figure 2a shows the schematic of a chain-like actuator for a finger, which can also be applied to other fingers. It is mounted on a rubber glove and one end of the chain is grounded to the body by a nylon tape around the wrist. The other end is attached to a ring around the fingertip. During voluntary motions of a human operator, the actuator is controlled to follow the motions. As soon as the human operator touches a virtual object, the actuator is deactivated and tries to contract to its initial shape. Thus, a resistance force is generated via the ring onto the ventral side of the fingertip, blocking the finger's motion.

Figure 2b shows a demonstrator of the chain-like actuator. Several elementary actuators are connected in series to form a chain. In principle, each elementary actuator works the same as the aforementioned dielectric elastomer actuator. However, the output is restricted only in the longitudinal direction, which contributes to the final elongation or contractile force outputs of the chain. An elementary actuator comprises four parts: a *dielectric elastomer film*, a *fixture* that holds the pre-tension, *compliant electrodes* and *connectors* that feed the actuator.

4 Actuator manufacturing

The manufacturing process of a single-layer elementary actuator is briefly introduced in four parts.

