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Enabling portable multiple-line refreshable Braille displays with electroactive elastomers

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ABSTRACT

Full-page (multiple-lines), electrically refreshable, portable and affordable Braille displays do not currently exist. There is a need for such an assistive technology, which could be used as the Braille-coded tactile analogue for blind people of the digital tablets used by sighted people. Turning those highly desirable systems into reality requires a radically new technology for Braille dot actuation. Here, we describe standard-sized refreshable Braille dots based on an innovative actuation technology that uses electro-responsive smart materials known as dielectric elastomers. Owing to a significantly reduced lateral size with respect to conventional Braille dot drives, the proposed solution is suitable to array multiple dots in multiple lines, so as to form full-page Braille displays. Furthermore, a significant reduction also of the vertical size makes the design suitable for the development of thin and lightweight displays, thus enabling portability. We present the first prototype samples of these new refreshable Braille dots, showing that the achievable active displacements are adequately close to the standard Braille requirements, although the force has to be further improved. The paper discusses the remaining challenges and describes promising strategies to address them.

1. Introduction

The world's roughly 314 million blind and visually impaired people are largely excluded from today's digital revolution in information and communication technologies. Indeed, displays of computers, portable devices, touch screens and so forth are conceived to bring text and images via the sense of sight.

Visually impaired people can access digital information only via text-to-speech readers. However, conveying information using sound is not always effective. Indeed, the interpretation of text based only on listening might be limited, for example, by the impossibility of a continuous backtrack. Furthermore, the presence of other people nearby might require the use of headphones to protect privacy or not to disturb, whilst a noisy environment might provide an additional challenge.

Overcoming these problems requires refreshable Braille displays. They are conceived as electronically controllable tactile interfaces allowing blind users to read text presented in the Braille code via dots that are dynamically raised and lowered. In particular, full-page displays would allow blind people to access via the sense of touch large amounts of structured and dynamic information, like sighted people commonly do via the sense of sight, for example when using computer monitor displays, tablets and smartphones. In other words, full-page displays are needed as the Braille-coded tactile analogue for the blind people of the displays used by the sighted people to visualise text and images.

Commercially available refreshable Braille displays are based on piezoelectric reeds that actuate the Braille dots. The reeds are mounted as a stair stepped stack of cantilevers, each with a Braille pin resting on its free end [1]. This solution limits the whole display to a maximum of two lines of Braille characters [2], which makes backtracking impossible while reading a full page of text. To overcome this limitation, attempts to develop full-page Braille readers based on different types of piezoelectric actuators are in progress, although the only available system developed so far is non-portable and has an estimated cost of about € 60,000 [3].

So, affordable, portable and multiple-line (full-page) Braille displays are needed, as they merely represent technological fiction today. They are required to facilitate access to digital information, as well as to help to improve the Braille literacy rate across the blind population, also with the aim of reducing its high unemployment rate [4].

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Table 1
Specifications of Braille dot parameters for refreshable Braille displays [1].

Dot parameter	Typical value
Base diameter	1.5 mm
Height (assuming no force from user's finger)	0.7 mm
Blocking force (dot raised within 0.1 mm of maximum height)	50 mN
Blocking force (dot raised 0.25 mm above reading surface)	150 mN

A paradigm shift from technological fiction to reality requires the ground-breaking creation of a radically new technology for Braille dot actuation. To this end, several alternatives to piezoelectric actuators have been studied. For instance, pneumatically actuated Braille dots with microvalves have been proposed [5], although the need for air pumping and individual dot control limits the portability of the resulting systems. Shape memory alloys have also been investigated as a method of providing actuation, although they show limitations in terms of size, speed and power consumption [6]. Linear actuators vertically pushing Braille dots have been prototyped using either rolled sheets of electrostrictive polymers [7] or tubes of dielectric elastomers [8], although the length of the actuators enlarges the size of the device.

Dielectric elastomer (DE) actuators [9–11] represent the electromechanical transduction technology used in this work too. They belong to the bigger family of electromechanically active polymers [12], which includes a diversity of smart materials studied for various biomedical applications [13]. The most basic configuration of a DE actuator consists of a thin elastomeric layer coated with two compliant electrodes, so as to obtain a deformable capacitor. A voltage V applied between the electrodes results in the following effective electrostatic pressure p on the elastomer surface:

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

where ε_0 is the dielectric permittivity of vacuum, ε_r is the elastomer's relative dielectric constant and d is the dielectric layer's thickness. This pressure causes a squeezing in thickness and a concurrent surface expansion [11].

The DE actuation technology in general offers attractive properties in terms of large strains, fast, stable and silent operation, compact size, low weight, shock tolerance, low power consumption and no overheating [9–11,14]. DE actuators show significant potential to develop compact, fast, lightweight and silent electromechanical transducers for tactile interfaces [14]. Studied configurations include cylinders [7,8,15], diaphragms [16], buckling membranes [17,18], planar multi-layer stacks [19] and bistable diaphragms [20]. Nevertheless, so far, none of these proposed configurations seems to be readily applicable to obtain commercially viable Braille displays. This is due to a number of challenges (specific to each approach), related to one or more of the following drawbacks: low forces, low displacements, low response speed, high cell thickness and overall encumbrance, high energy consumption, overheating, manufacturing complexity, short lifetime, low reliability (see details in the previously mentioned references).

Aimed at overcoming the limitations of these state-of-the-art approaches, this paper presents real-size refreshable Braille dots based on DE actuation. The design, working principle, fabrication and a preliminary electromechanical characterization are described in the next sections, following a reminder of the main technical requirements.

2. Technical specifications

The requirements in terms of dimensions and force for a standard Braille dot [1] are presented in Table 1.

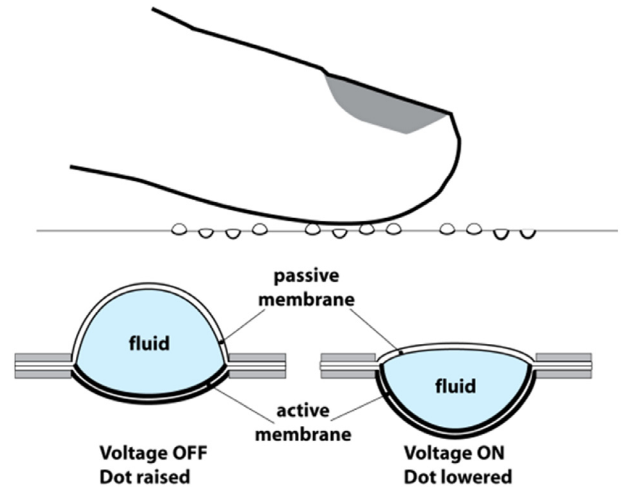

Fig. 1. Schematic drawing of the proposed concept. In order to obtain an array of electrically controllable compact Braille dots (top panel), each dot consists of a bubble-like HC-DE actuator (bottom panel). A lateral section of the actuator/dot is shown in the rest state (bottom, left) and in an electrically induced state due to an applied voltage (bottom, right).

According to these requirements, the raised Braille dot consists of a quasi-hemispherical cap.

Moreover, besides these geometrical and performance requirements, the dots' actuation technology should comply with electrical safety issues and allow for ease of miniaturization at low production costs, so as to enable compact and cost-effective systems.

3. Proposed concept and principle of operation

The concept is based on the particular type of DE technology known as 'hydrostatically coupled' DE (HC-DE) actuation [21]. HC-DE actuators in general are based on an incompressible fluid that mechanically couples a DE-based active part to a passive part interfaced to the load, so as to enable hydrostatic transmission. This general concept was used in this work to conceive a dynamic Braille dot as a bubble-like HC-DE actuator. The device is such that the actuator itself coincides with the dynamic Braille dot. The structure is shown in Fig. 1.

It includes the following parts: an electromechanically active membrane, made of a DE film coated with compliant electrodes; an electromechanically passive membrane, working as the end effector in contact with the finger (either directly, or via any interposed medium); an incompressible fluid contained in a chamber constrained by the two membranes. Both membranes are radially constrained by bonding them to a frame, in the region external to the chamber. The internal fluid is pressurised during manufacturing, so as to provide each membrane with the shape of a roughly spherical cap. The pressurised top membrane works as the Braille cell dot (passive interface with the user's fingertip). The pressurised bottom membrane behaves as a buckling DE actuator. The latter buckles outwards as a voltage difference is applied between its electrodes, while the passive membrane relaxes (as the pressure is reduced) and passively moves inwards, according to the fluid-enabled hydrostatic transmission (Fig. 1). Therefore, the dot is lowered or raised as a voltage is applied or removed, respectively. This principle allows for an electrically safe transmission of actuation from the active membrane to the finger, without any direct contact between them.

This basic structure can be replicated to implement a standard 8-dots Braille cell, as shown in Fig. 2.

Prototype dots were manufactured and tested as described in the next sections.

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