A PORTABLE PNEUMATICALLY-ACTUATED REFRESHABLE BRAILLE CELL

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Abstract: This paper reports a portable pneumatically-actuated refreshable Braille cell. The cell is based on a micromachined, kinematically-stabilized endoskeletal 2 x 3 microbubble actuator array with 1 mm pitch and 1.5 mm diameter. The fabrication process involves SU-8 inclined rotational UV lithography, micromolding, and stereolithography (SLA). The displacement is 0.56 mm and the generated force is 66 mN at 100 kPa applied pressure, respectively. The device has a maximum operating frequency of 200 Hz, suggesting potential uses not only as a Braille display but also for vibratory tactile applications, shape exploration, texture recognition, and other contact sensation-driven applications. The presented fabrication approach is scalable to a full page Braille display.

Keywords: Refreshable Braille display, Endoskeletal microbubble actuator, Pneumatic, Parylene

1. INTRODUCTION

Braille is a tactile language consisting of raised dots of varying arrangements that represent characters. One Braille cell, representing a single character, comprises an array of 2 x 3 dots. The international Braille building standard is shown in Fig. 1 as an example [1]. Each dot is 1.5 mm in diameter with pitch of 1mm between adjacent dots.

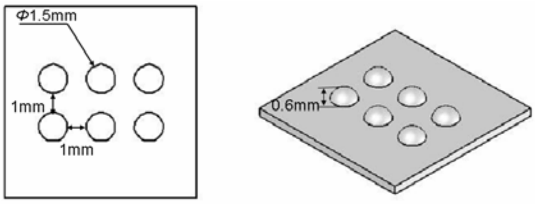


Fig. 1 International building standard for Braille cell.

A refreshable Braille display (RBD) is a device that converts text information from a computer to Braille dots for the blind to read. Most contemporary RBDs contain only a single line of 25 to 80 Braille cells due to the high manufacturing cost and large volume of piezoelectric bimorph actuators they utilize. Further, they are not portable because of their large size and weight. In order to develop a portable and multi-line RBD, a mass manufacturable, light weight, low power and integrable actuator must be developed. Several research groups turned to MEMS technology and different types of RBDs have been fabricated. Among them, the electrothermal RBD requires 50s to raise and retrieve a dot and no force data is reported [1]. A 6 x 4 array of sheet-type RBD based on an ionic polymer metal composite actuator has a maximum displacement of 0.4mm and 1.5gf generated force; however, it still requires 0.9s to reach 0.2mm displacement [2]. Pneumatic actuation is a promising candidate for Braille cell actuation due to its rapid response time and potential for large force generation while maintaining simplicity, scalability, and low cost. A valve for an elastic membrane type pneumatic RBD was demonstrated in [3]. In that work, an elastomeric membrane was actuated under a pressure load of 27.6 kPa. However, simple balloon type actuators do not fulfill the requirements of large force (50-100 mN) while confining the displacement primarily to the vertical direction (0.25-1 mm). Although forces available from such a membrane can be increased by increasing the driving pressure, conventional elastomeric membranes can become unstable under widely varying external loads (such as lifting of a finger), which limits the available force.

In this paper, an endoskeletal 2 x 3 microbubble array is employed as the actuation scheme for the

RBD system. By use of the endoskeletal bubble concept, the stability issues associated with simple elastomeric membranes are circumvented, allowing simultaneous achievement of the high force and high anisotropic vertical deflection required for RBD applications. Further, by minimizing overall bubble volume and maximizing overall bubble vertical deflection, the quantity of pneumatic gas used per cycle can be minimized.

2. DESIGN AND FABRICATION

The endoskeletal microbubble actuator consists of two polymeric layers with complementary functions: a microcorrugated parylene diaphragm layer as a “skeleton” to provide a directional deflection in a desired axial direction while suppressing the undesired lateral deflection; and an overcoated elastomer layer as a “skin” to help the extended membrane recoil to its original shape. The skeleton also enhances the stability of the microbubble during large inflations. A diaphragm design with 6 corrugations, an inclined angle of 17°, and a diameter of 1.5 mm has been adopted for the fabrication of the RBD actuators. A schematic view and the dimensions of the corrugated diaphragm are shown in Fig. 2.

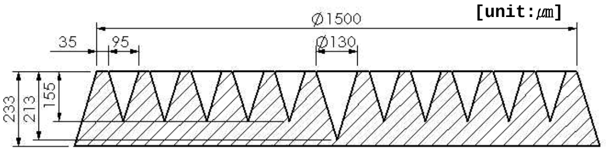
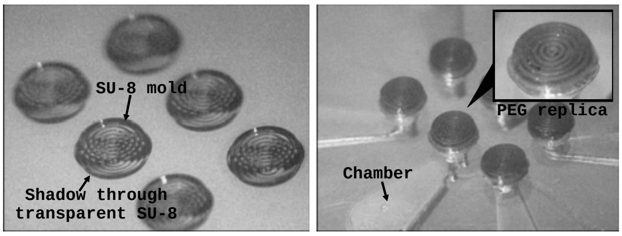


Fig . 2 illustrates the profile and dimension of corrugated diaphragms.

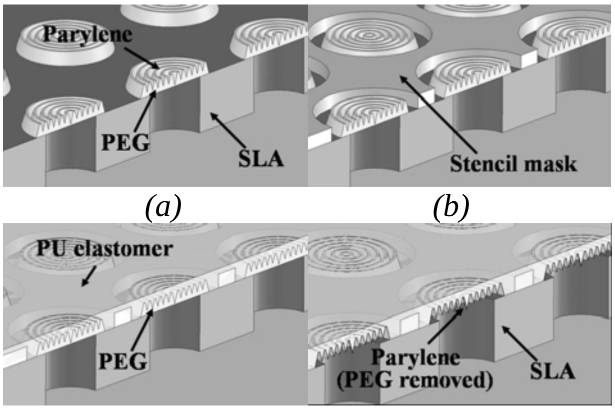
An array of sacrificial Polyethylene glycol (PEG) corrugated diaphragm molds on epoxy substrates are fabricated using inclined rotational UV lithography, micromolding, and pattern transfer technology. Detailed fabrication processes for the molds of Fig. 2 are described in [4]. Photomicrographs of the corrugated SU-8 molds and corresponding PEG replicates on a first stereo lithographically (SLA) – produced substrate are shown in Fig. 3.

After formation of the PEG replicas on the first SLA substrate, a parylene layer is conformally deposited on the PEG molds array (Fig. 4a). An epoxy stencil mask is placed on the epoxy substrate to planarize the top surface (4b). A thin layer of polyurethane (PU) elastomer is spin-coated on top and cured (4c).The sacrificial PEG is dissolved in water (4d). The epoxy substrate is then bonded to a second SLA manifold which pneumatically addresses each microbubble (4e). Finally, 3-way solenoid valves are assembled to the manifold to control individual actuators. The assembled device is shown in Fig. 5.



(a) original SU-8 mold (b) PEG replica

Fig. 3 Fabricated SU-8 mold and PEG replica



(a) (b)

(c) (d)

Fig. 4 Fabrication process

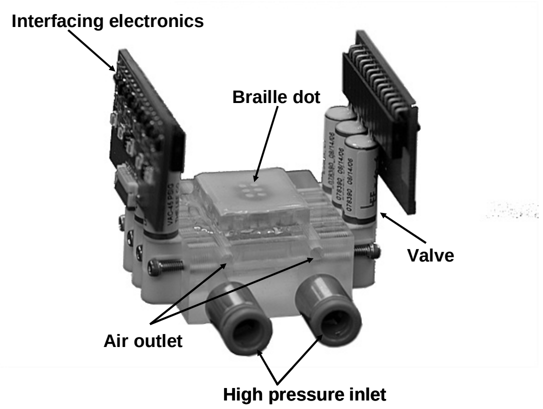


Fig. 5 Assembled device

3. CHARACTERIZATION

The performance of the RBD device is assessed from the following perspectives: spatial resolution, displacement, force generated, mechanical bandwidth, and pneumatic power consumption.

3.1 Spatial resolution

Fig. 6 shows selectively actuated Braille dots representing the characters “B”, “P” and “T” in American Braille style. The center-to-center distance between two adjacent dots is 2.5mm, which exceeds the minimum discernable distance of 2mm on a finger [5].

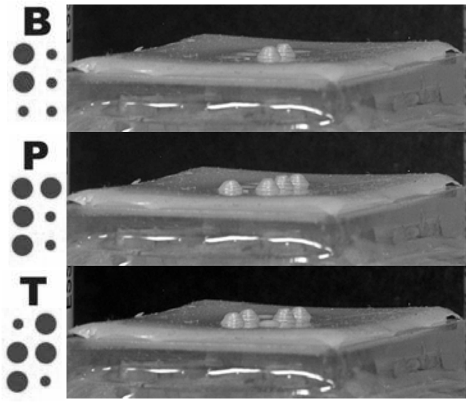


Fig. 6 Actuation of the Braille dots corresponding to the Braille characters

Magnified pictures of a dot in an inactivated and an activated state are shown in Fig.7. Note that large deflections are achieved preferentially in the vertical direction, which makes the shape more distinguishable than the hemispherical shape of a pure elastomer balloon actuator.

(a) unactuated dot *(b) actuated dot at 100kPa*

Fig. 7 Inactivated and activated Braille dot

3.2 Displacement

Center displacement of a Braille dot (i.e. the actuator) as a function of applied pressure has been quantitatively characterized using a laser displacement sensor. The results for a Braille dot with 2.5-um-thick parylene and 200-um-thick PU are plotted in Fig. 8. It shows that the maximum displacement of the dots without load is 0.56mm.

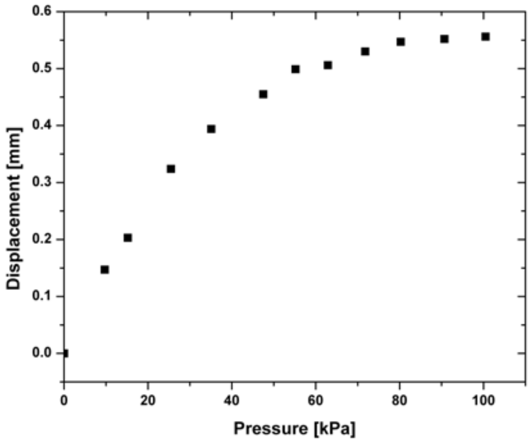


Fig. 8 Measured dot height as function of applied pressure

3.3 Force generated

Psychophysical experimental data indicates that a 50-100mN force is applied during a fine-touch object exploration [6]. Each Braille dot should withstand at least 50mN contact force while maintain at least 0.25mm displacement to be able to stimulate the shallowest mechanoreceptor. A force evaluation is carried out for the RBD device. As can be seen in Figure 10, a 10 gram and a 20 gram weight are lifted up to 0.43mm and 0.48mm by three actuated dots at 60 kPa and 100 kPa, respectively. That corresponds to 33mN and 66mN generated force per dot at 60 kPa and 100 kPa while maintaining 0.4mm displacement.

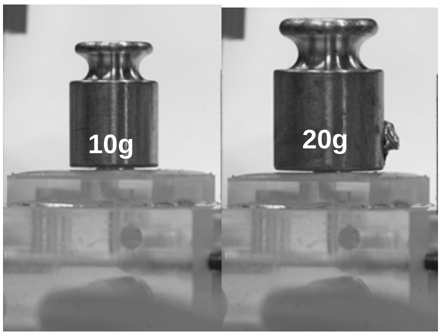


Fig. 10 A 10 g and 20 g weight is lifted by three actuated Braille dots

3.4 Mechanical Bandwidth

To test the bandwidth of the RBD, steady pressure of 100 kPa was provided to the pressure inlet of the RBD. A series of sine wave inputs of varying frequency were applied to the valve controlling a single Braille dot. The sinusoidal input was modulated by the binary transfer function of the mechanical valve and adjusted to 50% PWM duty cycle at the frequency of interest, producing a pseudo-square-wave pressure pulse to the dot. The peak-to-peak displacement of the dot was measured by laser sensor as a function of excitation frequency in the range 0.2 Hz to 200 Hz and plotted in Fig. 11 as a function of frequency.

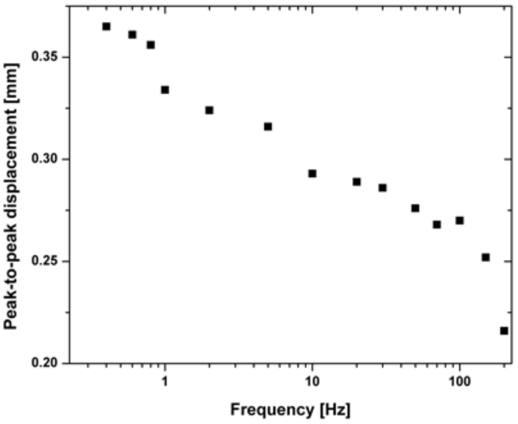


Fig. 11 Frequency response of one Braille dot

As seen in Fig. 11, at an actuation frequency of 30 Hz, the peak-to-peak magnitude has fallen to approximately 70% of its low frequency value. At 150 Hz excitation frequency, the peak-to-peak displacement is approximately 0.25 mm which still meets the minimum requirements for a Braille display. Further, at 200 Hz, the displacement of 0.22 mm is still more than 50% of the maximum 0.403 mm. The high frequency performance of this RBD cell suggests its application in a vibratory tactile display, since according to physiological study, the 200-300Hz range is the most sensitive range for vibration sensing by human skin [7].

3.4 Pneumatic power consumption

An approach to truly portable Braille displays involves on-board storage of pressurized gas. Based on the current design, we calculated that 1cc of 10atm compressed air can sustain 24 min of Braille reading at a 5Hz frequency for a single Braille cell.

4. CONCLUSION

This work has shown the development of a 2 x 3 pneumatic tactile actuator array for use in a Braille display. The tactile display can provide both a static display (which meets the displacement and force requirement of a Braille display) and vibratory tactile sensations. Along with the above capabilities the device was designed to meet the criteria of lightness and compactness permitting portable operation. The design is scalable with respect to the number of dots while still being simple to fabricate. Future work will involve basic psychophysics experiments to evaluate its performance in Braille reading, user shape recognition and other tactile perception.

5. ACKNOWLEDGEMENT

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