Refreshable Braille displays using EAP actuators

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ABSTRACT

Refreshable Braille can help visually impaired persons benefit from the growing advances in computer technology. The development of such displays in a full screen form is a great challenge due to the need to pack many actuators in small area without interferences. In recent years, various displays using actuators such as piezoelectric stacks have become available in commercial form but most of them are limited to one line Braille code. Researchers in the field of electroactive polymers (EAP) investigated methods of using these materials to form full screen displays. This manuscript reviews the state of the art of producing refreshable Braille displays using EAP-based actuators.

Keywords: Braille, Refreshable Braille Displays, EAP, Electroactive Polymers, Biomimetics, Tactile Interfaces

1. INTRODUCTION

The World Health Organization (WHO) estimates that globally there are about 314 million people who are visually impaired with 45 million of them are blind. Reading is one of the issues that are constraining them and their ability to benefit from all the many things that seeing allows. The writing code, which is well known as Braille, carries the name of Louis Braille, who developed it in 1825. It consists of 6 raised dots per character arranged in a rectangular shape along two columns of 3 dots each (see **Figure 1 left**) allowing to form 64 combinations including the none raised dots. Particular permutations are described by naming the positions where dots where from top to bottom on the left are known as 1 to 3, and from top to bottom on the right are named 4 to 6. Horizontal Braille text is written along lines that are separated by a space so that one can differentiate the text in the above and below lines. Punctuations, numbers and upper case letters have unique set of representative characters. The extension of the Braille code to 8 dots (see **Figure 1 right**) with 2 rows of 4 dots provides 256 combinations and they are used to represent ASCII characters in a single cell.

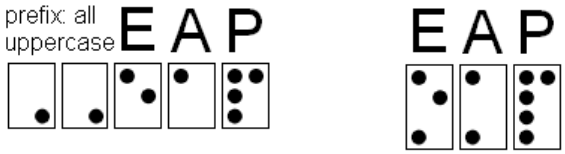

Figure 1: EAP in upper case expressed in Braille code in 6 and 8 dot systems [Runyan, 2009].

A standard Braille page is 11" by 11.5" (28 cm × 30 cm) and consists of 25 lines of 43 characters. Generally, the dot diameter in a Braille cell is in the range 1.27 to 1.65 mm and the height of a raised dot is approximately 0.5 mm. The force that is used in active dots is at least 0.15 N [Kato et al., 2007; Matysek et al., 2009]. The minute dimensions of the code pose great challenge to the developers of refreshable Braille displays [Runyan and Nassimbene, 1974] and EAP actuators offer great potential to producing such displays [Bar-Cohen, 2010].

2. HISTORICAL PROSPECTIVE OF ACTIVE BRAILLE DISPLAYS USING EAP

In 1998, the author conceived a refreshable Braille display that is driven by EAP and documented it in a NASA New Technology Report [Bar-Cohen, 1998]. Later, he included a description in his book about EAP that was first published in 2001 and now available in its 2nd Edition [Bar-Cohen, 2004]. The concept that the author documented [Bar-Cohen, 1998] consists of a sheet of EAP material with a planar array of small "reading pins" (see **Figure 2**). Under computer control, the reading pins are lowered individually or in groups to produce a tactile pattern of high and low dots representing the information to be read. Reading the pattern is done by brushing across the display with the fingers. The pins are lowered by an EAP film made of such an EAP as dielectric elastomer [Bar-Cohen, 2004] that contracts when

subjected to an electric field. The reading pins are mounted on the film and to protect the user from electric shock an electrically insulation in the form of a rubber film covers the actuator. A selected reading pin is lowered by applying a voltage across the thickness of the EAP film at the location directly under the selected pin. Rows of electrodes on the top surface and columns on the bottom of the EAP film allow activating individual pins.

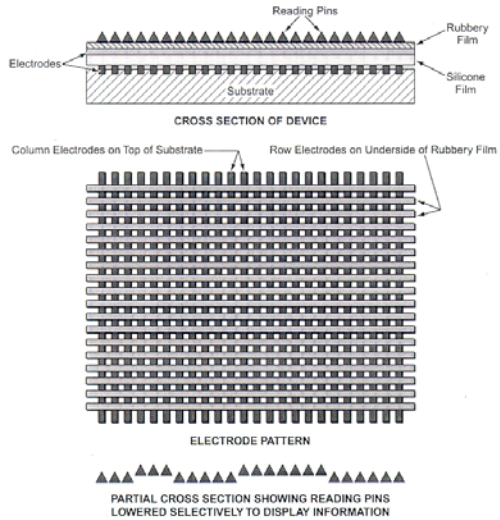

Figure 2: An EAP film with addressable pins at the intersection between selected row and column electrodes to which a voltage is applied [Bar-Cohen, 2004].

3. EAP BASED REFRESHABLE BRAILLE DISPLAYS

Following the author publications [Bar-Cohen, 1998; Bar-Cohen, 2004], other researchers started developing EAP actuated Braille displays and significant progress has been made. The developers are seeking to create devices that activate dots at the size of Braille cells [Bar-Cohen, 2010] and the reported studies are summarized in this Section.

3.1 Conducting Polymers

A two dimensional electronic Braille screen actuated by conducting polymers [Spinks et al., 2003; Ding et al., 2003a and 2003b; Spinks and Truong, 2005; Spinks and Wallace, 2009] is being developed by scientists at the University of Wollongong, Australia, in cooperation with Quantum Technologies, Sydney, Australia. An EAP actuator made of polypyrrole fiber and polyelectrolyte gel was designed to move dots vertically by axially contracting and expanding and a prototype consisting of four pins was produced. The change in elastic modulus of the actuator occurs when the polymer is oxidized and reduced causing length change. The goal for the speed of moving dots up and down is in less than 0.5 sec (preferably 0.2 sec). The distance the dot moves is 0.5mm, which equates to 1% strain in the initial design using 50mm long actuators. The resulting strain rate is up to 5%/sec. The actuators should last at least 106 cycles, be operated at low voltage (<20 V) and use minimal power. To enable the pins to be readable and refreshable the actuator is operated against a spring. While successful in meeting their goals for the actuator, there are still challenges to turning the preliminary prototype to production of a full screen and the key issue is fabrication of a screen with 8,000 actuators.

3.2 Ionic polymer metal composite (IPMC)

Researchers at the University of Tokyo, Tokyo, and the National Institute of Advanced Industrial Science and Technology (AIST), Osaka, Japan, investigated the use of IPMC as actuators of a sheet-type Braille display. To develop an active matrix display they created and integrated organic field-effect transistors [Kato et al., 2007]. The produced prototype consisted of 24 Braille letters using 6 pin cells with each pin being individually addressable by electrical activation. Dots in the form of 1.8 mm diameter hemisphere were attached to the tip of each actuator and the size of each actuator was 4 mm long by 1 mm wide. A 3 layer structure was used and the actuator was sandwiched between the layer of the electronics at the bottom and the top consisted of a thin sealing layer made of rubber. The display was tested by blind persons and while it was readable the IPMC actuators generated maximum force of 0.015 N, which is significantly below the required level of 0.5 N for adequate tactile sensation. The maximum displacement of the actuator at no load was 0.4mm and it was close to the task target of 0.5mm. The response time of the actuators is several seconds and the relaxation to the start state upon removal of the voltage is slow.

3.3 Diaphragm-actuator using Dielectric Elastomer EAP

Researches at SRI International are developing an active Braille display using a diaphragm that is made of a dielectric elastomer EAP. A very thin polymer film (30 to 100 µm) with compliant electrodes formed the diaphragm that was supported to a substrate in the shape of a circle with air pressure providing prestrain for the attached pins (1.6 mm diameter) of movement [Heydt and Chhokar, 2003]. A driving voltage of 5.68 kV produced displacement of 450 µm and the measured force and displacement suggest that the developed approach is a viable one for making a refreshable Braille or tactile display. Given the response speed of dielectric elastomer EAP, this display is expected to provide the desired response time of 1-Hz. The fabrication of a low cost version is expected to be feasible using a simple 3 layer structure.

3.5 Diaphragm actuated by dielectric elastomer actuators

The use of dielectric elastomer actuators to drive a diaphragm was also investigated by researchers from the Sungkyunkwan University, South Korea [Choi et al., 2004; Lee et al., 2004; Choi et al., 2009]. A 50 µm thick bubble-shape arrangement was developed for which a dielectric elastomer produced an out-of-plane deformation pushing a pin vertically. The pre-stretching of the elastomer itself provides the required "spring" action for tactile sensation. In order to obtain large actuation force a 750 µm laminated membrane was stacked using rigid circumferential loop frame and the produced actuation system allows pushing pins [Choi et al., 2004]. The pin actuation system was miniaturized to the level that enabled the required pin density to stimulate human fingertips at a reasonable spatial sensitivity. A multilayer design was used with two plates of 3 actuators attached to each other and levers connected the actuators and pins. A prototype of two-cell display with 6 pins each was constructed and tested by blind subjects and a reasonable recognition rate was achieved.

3.6 Stack actuator made of dielectric elastomer

A stack actuator made of multilayered dielectric elastomer was developed by scientists at Darmstadt University of Technology [Schlaak et al., 2005; Matysek et al., 2009]. To determine its feasibility, the concept was analyzed in three-dimensions using finite element modeling and the displacement and dynamic behavior were investigated. It was determined that planar actuator arrangement in a hexagonal shape allows obtaining equal distance between all adjacent actuators to allow forming a full page display. Embedded bumps between the actuator and the human skin allow realizing the required force transmission and exciting a selected actuator is done by rows and columns of electrodes.

3.7 Bistable electroactive polymer (BSEP)

Scientists at UCLA in collaboration with NASA Ames Research Center have developed a bistable electroactive polymer (BSEP) that was demonstrated to activate a refreshable Braille display cell [Yu et al. 2009]. The actuation material that is used consists of a Thermoplastic poly(tert-butyl acrylate) (PTBA) EAP. This polymer provides bi-stability that is determined by the material temperature relative to the glass transition point allowing forming various shapes with large strains. Above the glass transition temperature the material acts as a dielectric elastomer and is deformed electrically and it is rigidized by lowering the temperature below this temperature. In its rubbery state and using actuation pressure of 3.2 MPa, a PTBA thin film can be electrically actuated to strains of up to 335% in area expansion. To form a Braille cell a diaphragm actuator was fabricated using 30 µm thick PTBA films with conductive carbon grease coating as compliant electrodes. At 70 °C no deformation was observed and upon driving the film by about 2KV a dome shape was formed. To create a Braille cell the diaphragm was shaped as six-dot and the dots were selectively activated and their shape was locked by removing the heating current. Measurements have shown a force of 0.6 N force applied vertically on the top of the domes with a response speed (full cycle of heating and cooling) typically about 40 s allowing also to refreshes the display.

3.8 Piezoelectric polymer based on PVDF

Investigators from North Carolina State University [di Spigna, et al., 2009] are using both polyvinylidene fluoride (PVDF) and silicone dielectric elastomer cylindrical tube actuators to develop a full page refreshable Braille. For this purpose, film actuators were designed with planar bending mode using lithography techniques to produce miniature bimorph PVDF actuators. The bimorphs were biased with less than 1KV and were demonstrated to raise Braille dots at 10Hz. The actuator was designed to be filled with hydraulic fluid in order to transfer the bimorph movement to a vertical tip displacement of a rod. Once the tip head reaches the desired height, a support block moves underneath and mechanically locks the structure in this extended shape. To lower the tip head, the actuator voltage is reversed forcing the bimorphs to bend outward pulling the block and returning the tip to the initial position.

3.8 Roll-actuator made of terpolymer ferroelectric EAP

Recent progress in making Terpolymers allowed researchers at Penn State University to make an actuator for moving pins in order to produce an active Braille display. A pin was connected to a base plate using an actuator roll made of poly(vinylidene fluoride-trifluoroethylene-chlorofluoro- ethylene) (P(VDF-TrFE-CFE)) [Ren et al., 2008]. A screen printing deposition method was developed to directly and rapidly deposit electrodes in the form of very thin conductive polymer electrode layer (<0.1 μm) that was strongly bonded to the terpolymer surface. A roll actuator was designed and fabricated as a 60 mm long and 1.37 mm outer diameter with spring core to provide tactile resistance. To generate sufficient force that activates the spring a multi-layer film structure was made using 6μm layers. At field strength of 100 V/μm the compressed spring deflects more than 1 mm and carries a load of 0.75 N. Test results demonstrate the feasibility of to actuate pins and to meet the functional requirements of an EAP activated Braille display

3.9 Braille printer using refreshable shape-memory polymer (SMP) paper

At the Harbin Institute of Technology, China, a Braille printer is being developed using thermoplastic refreshable shape-memory polymer (SMP) paper [Leng et al., 2010]. The device consists of five components including: (1) A metal board with holes; (2) SMP-made Braille paper; (3) Resistive heating pen with a protuberance on the tip; (4) Recovery plate using resistive heating; and (5) Ruler with through-holes guiding the pen positioning. The printing process consists of heating the SMP paper to soften it and the holes on the metal board and the protuberance on the printing pen conform to allow imprinting hemispherical convex dots on the SMP paper. The printed code can be "erased" by reheating the SMP paper with approximately 95% recovery ratio [Leng and Lan, 2010].

4. CONCLUSIONS

Making an EAP actuated Braille displays that are effective and inexpensive is very important to allowing visually impaired to take greater benefits from the digital technology and the various user interface tools. Developers from Australia, China, Germany, Korea, Japan and USA investigated various designs using such materials as the IPMC, Conducting Polymers, Ferroelectric EAP, Dielectric Elastomer EAP and SMP. Efforts are made to closely package many actuated pins to enable full screen display in the specifications of existing Braille text standards of cell with 6 and 8 pins. The reported actuators move levers, rolled film over pre-strained spring, bimorph configuration, multi-layered array and a diaphragm with spring backed elements taking advantage of the pre-strain. While the developed displays showed significant advances towards meeting the required specifications there are still many challenges that hamper the development of commercial devices. The challenges include the need for low actuation voltage for the field activated EAP actuators and the low generated force of IPMC. Advances in developing more effective EAP materials and related processing techniques may lead to effective refreshable Braille displays.

5. ACKNOWLEDGEMENT

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