4x4 Fingertip Tactile Matrix Actuator with Edge Detection Scanning ROI Simulator

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***Abstract*—This study presents a novel 4x4 fingertip tactile matrix actuator that can be strapped on a finger. It is made from Dot Braille cells purchased from Dot Inc., Korea. The prototype has a surface area of 1.08 cm^2 with a pin pitch of 2.6 mm and operates at 5V supply. Each tactile pin can be controlled using an h-bridge motor driver and Arduino microcontroller. The tactile matrix is coupled with a tactile matrix simulator that scans a binary image or edges of an image using Canny edge detector. The simulator has 16 sections corresponding to the 16 actuator pins. The integration of the simulator to the hardware prototype allows the user to feel a binary image of a plane geometric figure or to feel the edges of an image as the scanning region of interest (ROI) moves across the visual screen. This fingertip tactile matrix display would be useful in many Virtual Reality (VR) applications to provide tactile feedback on the textures of virtual objects. Therefore, the authors suggest that this device will be beneficial in many applications such as virtual surgery, virtual fashion, remote sensing, and telerobotics.**

***Index Terms*—tactile matrix actuator, edge detection**

I. Introduction

Research on haptics and tactile transducers is an interdisciplinary field that covers perception [1], psychophysics [2], vision substitution system for the blind and visually impaired [3], [4], virtual reality (VR), mechanism design and control, bio-medical engineering, mobile communication [5], telerobotics [6], [7], material recognition [8], and human-computer interaction (HCI) [9].

Tactile transducers in the form of displays and vision substitution systems have a long history that dates back to their development in the 1960's [3], [4], [10]. A tactile display is a human-computer interface that can reproduce tactile parameters of an object, such as shape, surface texture, roughness, and temperature [11]. Tactile displays can be interfaced with other electronic devices such as computers [3], [4], communication media, mobile phones [5], and car appliances. It has also been used in e-commerce, telepresence [6], [7], and virtual reality (VR) applications [12], [13]. They are built with a number of pins (taxels or tactile pixels) [12] which can be lifted or lowered forming a matrix of pins arranged by lines and columns. Compared to Braille, tactile display pins are not grouped. All pins have the same displacements to the neighboring pins so that no gaps will emerge when displaying graphics [12], [13]. In a Braille-like tactile displays, the user needs to move their hand to explore the activated pins. On the other hand, in a miniature fingertip tactile matrix however the finger moves a little because the fingertip covers the whole area of tactile pin matrix. Each pin in a tactile matrix actuator can be activated in an 'up' or 'down' position, and can vibrate at different tapping frequencies [14], [15].

Tactile displays come in different sizes and pin numbers (3x3 to 64x72) [15], [16] with a wide variety of different types of tactile actuators such as: solenoids [4], [12], [13], [17], [18], [21], vibration motors [10], [15], and voice coil motors [22], piezoelectric (bimorph and small ultrasonic linear motor) [3], [23]–[25], smart memory alloy (SMA) [26], [27], shape memory polymer (SMP) [28], pneumatic [29], [30], and stepper motor [31] for 3D solid pattern.

Recent research on haptics and tactile feedback tend to focus on miniaturization of tactile matrix actuators [17] and combining haptics with virtual reality (VR) in order to provide a more immersive experience [12], [17], [18]. According to [18], aside from vision and audio, the development of the portable tactile display is needed for all VR technology. Haptics and tactile feedback can enhance control system and sensor system integration [19], [20].

This paper presents a novel 4x4 fingertip tactile matrix actuator with a tactile matrix simulator that scans a visual display and gives the user a tactile sensation of the edges of an image. Details on the prototype are discussed in the following sections: construction of prototype in section II, experimental setup in section III, evaluation of results in section IV, followed by conclusion and recommendation in section V.

II. Construction of the Prototype

The construction of the 4x4 fingertip tactile display focuses on two categories: hardware and software. Detailed discussions on these categories are as follows:

A. Hardware: 4x4 Fingertip Tactile Matrix Actuator

This section focuses on the use of a compact and miniature 2x4 Dot Braille cell [32]. Detailed schematics of the cell is shown in Fig. 1. The 2x4 Dot Braille cell operates at 5-Vdc supply and each pin can be controlled by an Arduino and h-bridge motor controller. Each pin has a solenoid and can be actuated "up' or 'down' depending on the direction of the current flowing on it. Each pin has a locking mechanism that makes it stay "up' or 'down' even after the power is shut off. This locking mechanism makes this device energy efficient

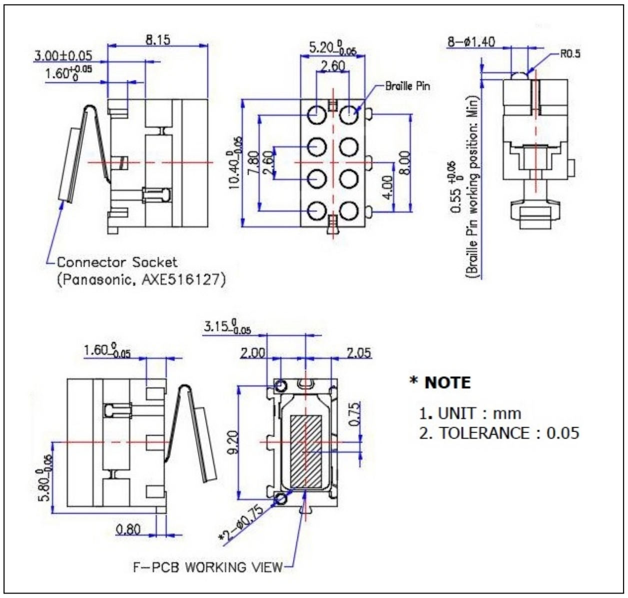

Fig. 1. Dot 2x4 Braille cell specifications [32].

and portable miniaturized fingertip tactile display that can be moved in any direction or orientation when strapped on a finger.

A 3D image of the 2x4 Dot Braille cell is shown and Fig. 2a. Two pieces of these cells can be assembled together to form a 4x4 tactile matrix with a side length of 1.04 mm. The assembly instruction on how to combine two cells is shown in Fig. 2b.

The building blocks of a 4x4 fingertip tactile matrix actuator prototype in this study is shown in Fig. 3. We used Arduino Mega microcontroller to give an 'up' or 'down' control signal to the 1.5A 2-channel MX1508 h-bridge DC motor driver modules that control the direction of current for each pin of the Dot Braille cell.

B. Software: 4x4 Tactile Matrix Simulator

The firmware that controls the actuation of the 4x4 tactile matrix actuator runs using Arduino IDE. On the application layer, we developed a 4x4 tactile matrix simulator using

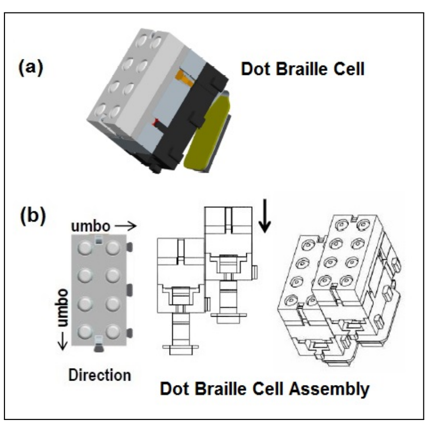

Fig. 2. Dot 2x4 Braille cell assembly [32].

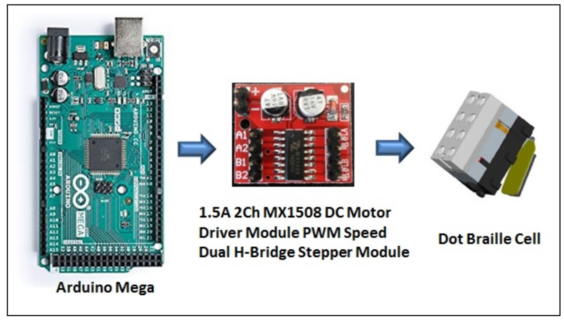

Fig. 3. Fingertip tactile matrix actuator building blocks.

Python. The tactile simulator is a square graphical user interface (GUI) forming a Region of Interest (ROI) with 16 small sections (red circles) representing the 16 tactile pins. The ROI can move across an image on the computer display using computer mouse. Each small section in the ROI evaluates the average black or white pixel color within its boundary. The simulator can be used to scan a binary image of a regular polygon edges of an image using Canny edge detector.

If the small section, as shown in Fig. 6, is more than 50% black, this small section of the ROI is filled with color yellow and an 'up' signal is sent to the microcontroller to activate the corresponding tactile actuator pin. Moreover, if the small section is less than 50% black, this small section of the ROI sends a 'down' signal to pull down the corresponding pin. The flowchart for the scanning ROI algorithm is shown in Fig. 4.

III. Experimental Setup

The experimental setup is shown in Fig. 5. Inside the control box are the motor driver modules and the Arduino Mega microcontroller. The connecting wires between the 4x4 tactile matrix actuator can be adjusted to make longer or shorter

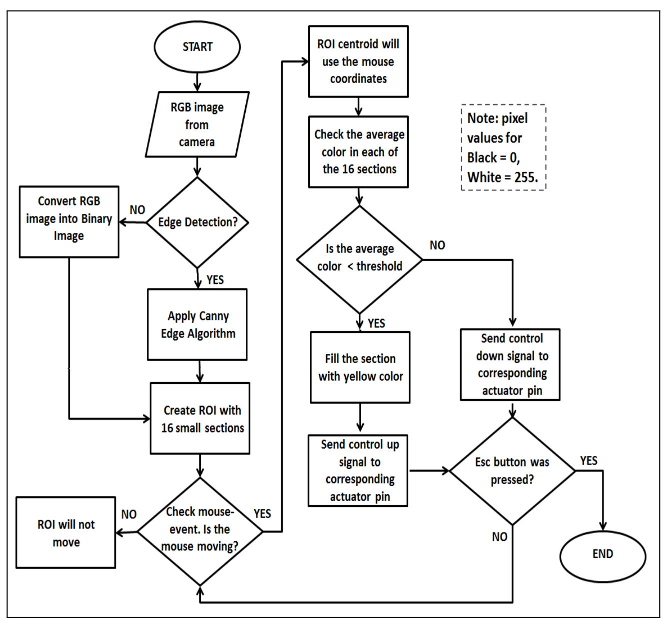

Fig. 4. ROI algorithm flowchart.

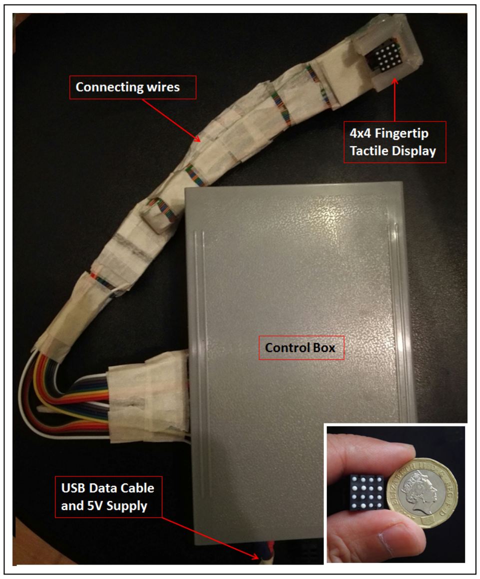

Fig. 5. 4x4 Fingertip tactile matrix actuator experimental setup.

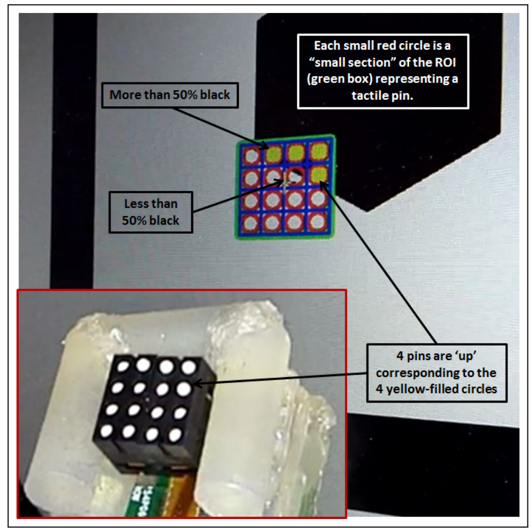

Fig. 6. 4x4 tactile matrix actuator simulator and 4x4 fingertip tactile matrix actuator prototype.

depending on the user preference. The 4x4 fingertip tactile matrix actuator has a side length of 1.04 mm with a pin pitch of 2.6 mm.

IV. Experimental Results

The 4x4 tactile matrix actuator simulator scanning ROI is shown in Fig. 6. It is the green square containing 16 small circles on the black and white image. Each small section within the ROI checks if the average pixel value is more than 50% black to change its color to yellow and send the 'up' signal to the corresponding actuator pin. This thresholding can be observed in upper two rows with yellow filled sections of ROI. The actual 4x4 fingertip tactile prototype is at the bottom-left corner of Fig. 6. Four pins are in the 'up' position corresponding to the 4 yellow-filled circles of the 4x4 tactile matrix actuator simulator scanning ROI. Fig. 6 shows the scanning of a regular shaped geometric figure or polygon.

Scanning binary image of a color-filled regular polygon gives the perception of touching a surface area. Moreover, this simulator can be combined to Canny edge detection algorithm that can trace the edges of an image within the ROI as shown in Fig. 7. The RGB picture in Fig. 7a was converted to gray scale and morphological transformation such as Gaussian blur was done before applying Canny edge detector.

The edges using a Canny edge detection are in white color with a black background as shown in Fig. 7b. Because our tactile simulator detects black color edges as an 'up' signal, we invert Fig. 7b to achieve edges in black lines in white background as shown in Fig. 7c. Using Hough transformation in OpenCV, the Canny edge lines can be thicken as shown in Fig. 7d. After the lines have been thicken, we apply our tactile simulator to sense the edges of a flower or the curved edges of a fingertip as shown in Fig. 7f. Our tactile matrix simulator works well not only on regular geometric figures but also on irregular shapes with curvy edges.

V. Conclusion

In this study, a 4x4 fingertip tactile matrix actuator made from Dot Braille cells was presented. It has surface area of 1.08 cm^2 with a pin pitch of 2.6 mm and operates at 5V supply. Each tactile pin can be controlled using an h-bridge motor driver and Arduino microcontroller. The firmware that controls each tactile pin was programmed using Arduino IDE. A 4x4 tactile matrix simulator corresponding to the 4x4 tactile actuator was developed as a GUI that can move across a visual display using a computer mouse. The simulator can be used to scan a regular shaped geometric figure to feel the surface area. It can be also be used to detect the edges of an irregular-shaped image. The prototype developed in this study might be used in the fields of telerobotics, VR, and HCI to enhance our immersive sensing experience.

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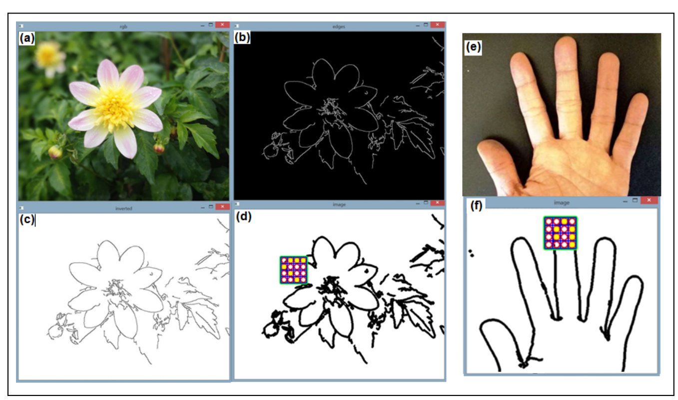

Fig. 7. Edge detection using Canny edge detector in a scanning ROI.

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