A WEARABLE BRAILLE RECOGNITION SYSTEM BASED ON HIGH DENSITY TACTILE SENSORS

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ABSTRACT

This paper reports a wearable and wireless system for Braille recognition, called TouchReader, which utilizes a fast and accessible strategy to facilitate visually impaired people in learning and communication. This finger-worn device is composed of flexible and piezoresistive sensor array with high density (96 sensors in 78.5 mm^2), high sensitivity (8.44 kPa^{-1} in low pressure range) and a template-matching recognition system. It is the first time to achieve area-scanning of Braille character on the strength of tactile sensors and convert text to voice message, exhibiting better practicability, portability and reliability in daily routine with less manual intervention.

KEYWORDS

Piezoresistive sensor, wearable interface, Braille recognition, high density, template-matching.

INTRODUCTION

Accessibility has always been a challenge for visually impaired people. The loss of vision makes reading and writing in traditional ways impossible for them, but there is another irreplaceable and worldwide method to be literate by the means of Braille. Every full Braille cell consists of six dots with specific size, positioned at two parallel lines and can be read with fingers. Sixty-four combinations between the raised and flat dots are represented different alphabet letters, numbers and punctuation marks. Therefore, it is a precise logical code tool to translate many languages, such as English, Spanish and Chinese.

However, it usually takes several years to acquire proficiency in Braille literacy, especially for the children and the elderly with vision loss, which impedes the participation of them at home and in society. Besides, the accuracy of the Braille recognition by the finger would dramatically decrease after prolonged reading, resulting in low efficiency of information acquisition and communication with other people. Hitherto, a multitude of available technologies have been proposed to solve the problem. One mainstream strategy is depended on computer vision algorithm, which captures Braille images by a micro camera and figures out the most similar character by image recognition algorithm [1]. However, some manual pretreatments and intervention are inevitable to deal with the problems including alignment, focus, or non-perpendicular page orientation. Moreover, micro cameras cannot work normally in non-ideal surroundings, such as moist and low lighting environment. The other strategy is based on tactile sensor to detect the partially raised points of a Braille character and convert it into electric pulses versus time [2, 3]. But the limitation of such strategy is that it only allows the user to read the character from the first line to the third line at a constant speed, which is cumbersome to operate. Thus, a convenient and smart Braille recognition system with high accuracy and mobility is quite necessary and imperative in daily routine.

In this work, we presented a wearable and smart Braille recognition system, called TouchReader, which combines tactile perception and auditory perception together to achieve vision compensation for visually impaired people. The working mechanism of the Braille recognition system makes use of tactile sensor array as the detecting part and template-matching algorithm to achieve the recognition. As shown in Figure 1, the 8×12 flexible tactile sensor array is attached on the fingertip of the user. When the user touches the Braille characters successively, the resistance response caused by the raised dots of the Braille would be recorded by map scanning. Next, the data of voltage is converted into Braille character by template-matching algorithm in the sensing circuit, which is integrated on a wristband. Finally, the recognized results would be converted into voice message, assisting the visually impaired people in understanding the daily information.

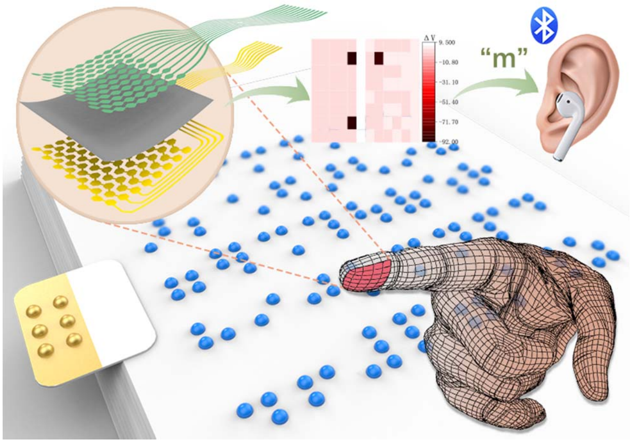

Figure 1: Overview of the TouchReader Wireless System for Braille Recognition.

Compared with the strategy utilizing computer vision algorithm, the feasible components of TouchReader that eliminating the need for micro camera make it possible to recognize Braille in any surroundings, regardless of the light intensity and Braille layout. On the consideration of the particularity of the visually impaired people themselves, less manual intervention involved, greater accessibility would become reality. Furthermore, the template-matching algorithm of TouchReader constructs a one-to-one corresponding relationship between eigenvector of Braille and English alphabet, so different eigenvector libraries of other languages could be integrated in the sensing circuit on the basis of the coding rules, to help the blinds read Braille books or markers in foreign languages.

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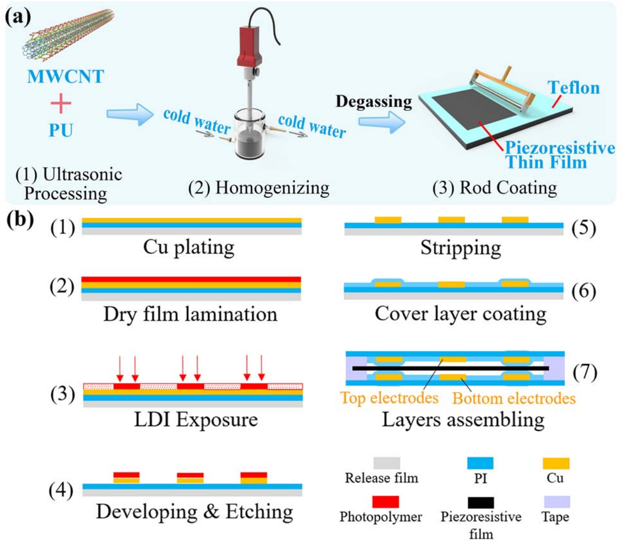

Figure 2: (a) Schematic illustration of the material synthesis of MWCNT@PU nanocomposite. Step (1): ultrasonic processing of MWCNT and polyurethane solvent for pre-dispersion. Step (2): physical mixing by high shear dispersion emulsification homogenizing with a speed of 10000 rpm under ice bath. Step (3): rod coating of the nanocomposite on Teflon film. (b) Fabrication process of row and column electrodes (1-6) and assembling of the tactile sensor array (7).

EXPERIMENTAL METHODS

Fabrication of the Tactile Sensor Array

The fabrication process of the tactile sensor array in this study is composed of two stages: the synthesis of piezoresistive nanocomposite and manufacturing of the row and column electrodes array. The first stage is schematically illustrated in Figure 2a. The multi wall carbon nanotubes (MWCNT) aqueous slurry was preprocessed by bath ultrasonic for 15 min and the polyurethane (PU) solution was magnetic stirred for 30 min at room temperature in order to obtain a stable dispersion. After adding the MWCNT aqueous slurry into PU solution with a weight ratio of 1.5 % in a double beaker, it was cooled by cold water circulator at the temperature of 10 degrees centigrade. Then, a high shear dispersion emulsification homogenizer with 10000 rpm was employed to intensively mix the carbon nanotubes aqueous slurry and PU solution for 15 min. To eliminate a mass of air bubbles in the mixture produced by homogenizing, it was degassed for 15 min. The above processes of homogenizing and degassing were repeated for 5 cycles altogether. Finally, the nanocomposite was rod coated on a Teflon film and cured in an oven at 80 degrees centigrade for 2 h.

The top and bottom electrodes were fabricated by a typical flexible printed circuit (FPC) technology, as shown in Figure 2b. Copper was electroplated on the polyimide (PI) substrate as conductive material. Then, the dry film which is composed of polyester (PE), photosensitizer and polyethylene glycol terephthalate (PET) was laminated on the copper as a function of protective layer. After exposure, developing and etching, 12 parallel column electrodes and 8 row electrodes with zigzag routing and hexagonal pads were finished, which could improve the density of the array. Finally, the piezoresistive nanocomposite film was sandwiched between the top and bottom layer by tape with a total thickness of 90 μm.

Design of the Braille Recognize Sensing Circuit

The high density tactile sensor array aforementioned is the key sensing part of the Braille recognize system, which transfers the pressure variation into corresponding voltage map when users touch the Braille character. In the sensing circuit, a multiplexer is connected with eight row electrodes to switch one of the electrodes to a grounding electrode and a microcontroller (ESP32-PICO) is employed to scanning the voltage values. The 8×12 voltage map is partitioned into six units, and numbered from left to right and top to bottom. First, we built a twelve dimensional eigenvector U to represent the tested Braille character. U is summarized as follows:

$$U = [u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8, u_9, u_{10}, u_{11}, u_{12}] \quad (1)$$

where u_x (x=1, 2, 3, 4, 5 and 6) is equal to 1 when there is a Braille dot in this unit, otherwise u_x is equal to 0; u_7 is the sum of u_1 to u_6; And u_8 is equal to u_1 plus u_2; u_9 is equal to u_3 plus u_4; u_{10} is equal to u_5 plus u_6, which means the number of Braille dots in every row. Similarly, u_{11} is the sum of u_1, u_3, and u_5; and u_{12} is the sum of u_2, u_4, and u_6, which means the number of Braille dots in every column. Secondly, we built a standard eigenvector V of Braille alphabet from A to Z and number 0-9, which defines as the same rule of U. Next, the Euclidean Distance d is introduced to find the most possible character and it can be calculated as the follows:

$$d = \sqrt{\sum_{i=1}^{12}(u_i - v_i)^2} \quad (2)$$

where u_i and v_i are the eigenvector component of U and V, respectively. The most similar Braille character under tested can be determined by the minimal d. Finally, this character will be displayed on an Android app and be converted into auditory signals, followed by sending to the blind users' earphones by Bluetooth (Figure 6b).

EXPERIMENTAL RESULTS

Sensing Characterizations of the Tactile Sensor

The transmission electron microscopy (TEM) was employed to observe the distribution of MWCNT in the PU, as shown in Figure 3a, which directly determines the performance of piezoresistive effect. It can be seen there is no obvious aggregate of MWCNT in the PU, which means

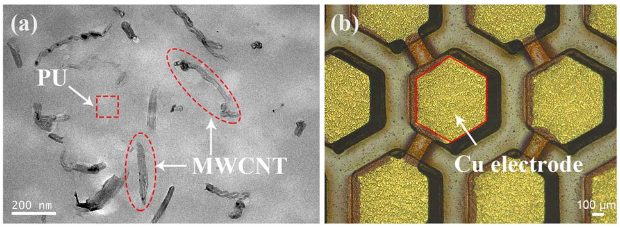

Figure 3: (a) High-magnification TEM image of MWCNT/PU nanocomposite. (b) Photograph of the bottom electrodes with zigzag routing and width of 100 μm.

well uniform conductivity of the piezoresistive film. The photograph of row electrodes with zigzag routing is presented in Figure 3b. The angle of zigzag routing is 120° and the number of pads in every row is increased by 33.4% under the same space distance of 0.27mm, compared with the straight routing. Therefore, the total density of the tactile sensor array is increased effectively, resulting in a more accurate performance of the tactile sensor array.

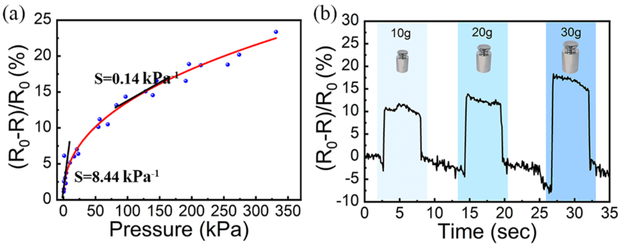

Figure 4: (a) Resistance response of the piezoresistive nanocomposite at the range of 0-350 kPa. (b) (R_0-R)/R_0 (%) of the tactile sensor under the weight of 10g, 20g and 50g.

The relative resistance variation versus the pressure on the flexible sensor is illustrated in Figure 4a. The pressure sensor made of MWCNT@PU nanocomposite has a wide measuring range from 0 to 350 kPa, which can well satisfy the common detection requirements of wearable flexible device. It can be seen that the flexible pressure sensor shows a sharp resistance decrease in the low pressure range (< 2 kPa) and it tends to decrease slowly when the pressure gradually grows to 350 kPa. The slope of the relative resistance variation is defined as the sensitivity of the piezoresistive sensor, which is commonly calculated as the follows:

$$S = \partial\left(\frac{R_0 - R}{R_0}\right) / \partial P \qquad (3)$$

where R_0 is the initial resistance, R represents the real-time resistance under pressure and P is the vertical pressure applied on the sensor. The sensitivity is estimated as high as 8.44 kPa^{-1} at the low pressure range, and gradually decline to 0.14 kPa^{-1} after the loading pressure exceeding 100 kPa. Generally, the typical pressure caused by the touching of a human's finger on a Braille character is less than 12 kPa, so the tactile sensor is working in the sensitive region. Furthermore, it can be seen from Figure 4b that three different weights of 10g, 20g and 50g were placed and removed on a tactile sensor, showing a proportional resistance variation. This pressure sensor can be utilized in many wearable devices, indicating the external pressure applied on the sensor.

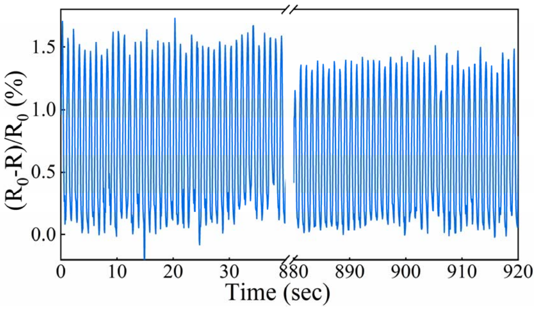

Figure 5: Fatigue testing under 11.9 kPa at 1 Hz for 1000 cycles.

Besides, the device stability and durability were performed by repeated loading and unloading cycles. The flexible pressure sensor presents a consistent resistance variation under 11.9 kPa at the frequency of 1 Hz for 1000 cycles, as shown in Figure 5.

Results of Braille Recognition System

Figure 6a is the photograph of wireless Braille recognition system. The inset picture exhibits the components of the wearable device. The flexible tactile sensor array is attached on the top of the index finger, and the ADC bleeder circuit and a development board ESP 32

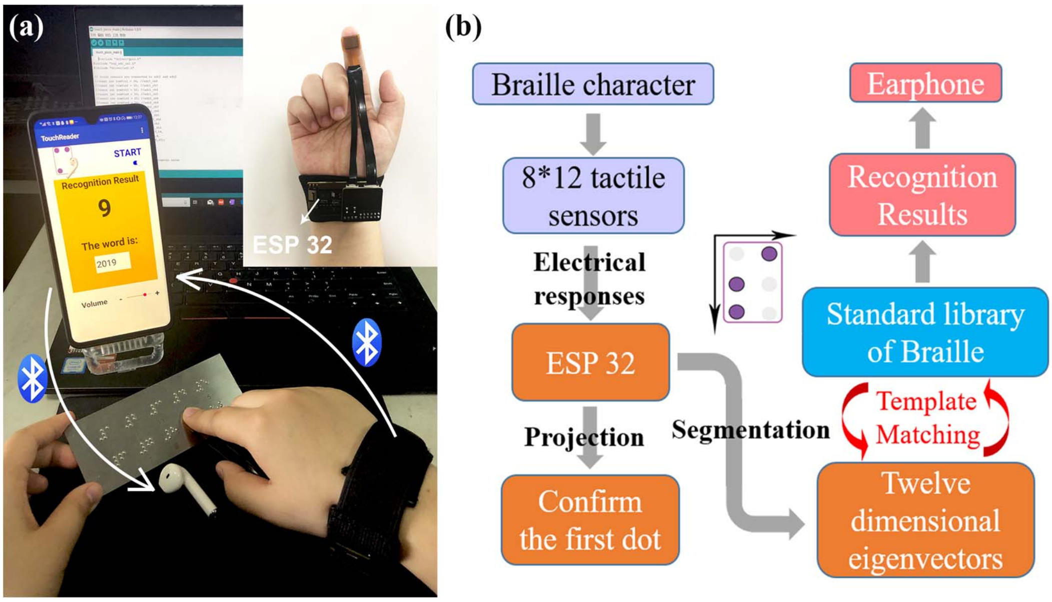

Figure 6: (a) The photograph of the wireless Braille recognition system. (b) Schematic of the template matching algorithm.

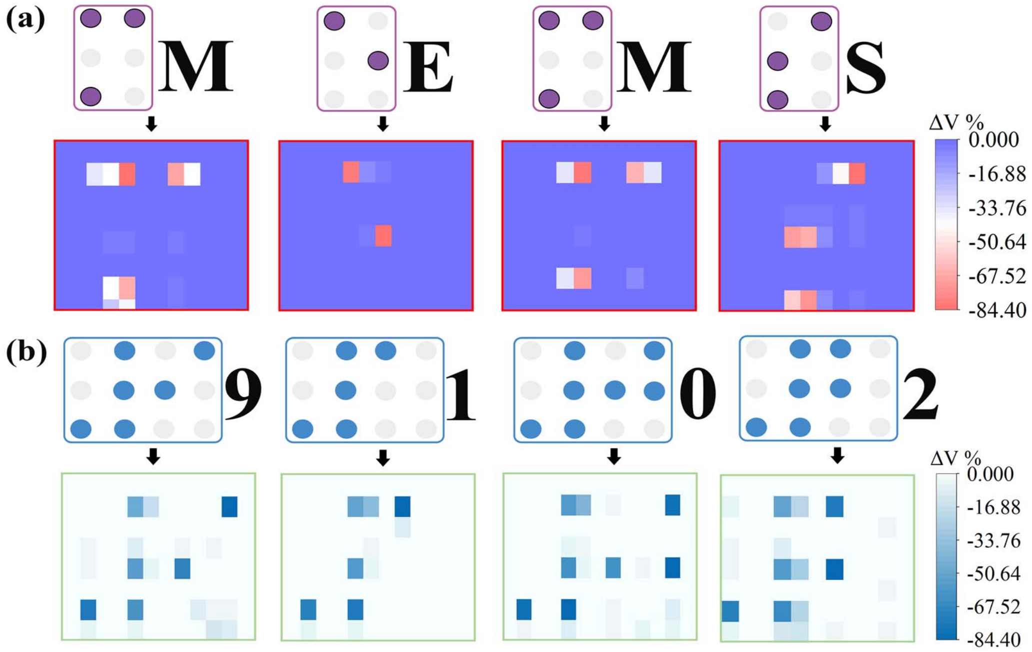

Figure 7: (a) Recognition results of the Braille alphabets M, E, M and S, respectively and (b) Braille numbers of nine, one, zero and two.

are fastened by a wristband. The total weight of this system is less than 100g, so it can be easily worn by any visually impaired people. When the user touched the Braille number 9 on a customized stainless steel board, which is easily found in daily life such as the elevator button, the Android app displayed the corresponding character on the screen and the earphone will show the signals to help the user confirm the Braille's meaning.

The testing recognition results of Braille alphabets and Arabic numerals are shown in Figure 7a and 7b, respectively. Every Braille alphabet is composed of six dots, whereas Arabic numeral is composed of twelve dots, and the left six dots remain unchanged, representing the symbol of Arabic numeral. The threshold of voltage variation is set as 20% for noisy filtration, which means a positive recognition result of Braille dot when the voltages decrease more than 80% of the full scale. The obvious voltage decrements in the 8×12 voltage map are in the same location with the Braille character, indicating an excellent uniformity in recognition. Although the response of a same Braille character is not identical in different time due to the minor variation from the force and contacting area cased by the finger, such as the two Braille "M" shown in Figure 7a, the maximum voltage variation remains and the recognition result is as same as the first result.

CONCLUSION

In this paper, we proposed a novel Braille recognition system which utilizes high density flexible tactile sensor array to accomplish area-scanning of Braille character for the first time. The template-matching algorithm used in this study constructs a one-to-one relationship between Braille character and English, and it can be expanded to other languages as long as built corresponding standard eigenvector library. It is worth mentioning that this wearable and portable TouchReader device has a comprehensive capability of tactile sensing, vision displaying and auditory transmitting, which can fully mobilize the user's perception and dramatically improve the efficiency of information acquisition for visually impaired people in their daily life.

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