The Development and Evaluation of a Color-Tactile Conversion App for Education of Visually Impaired

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Abstract
Pictures and diagrams play an important role in representing information and conveying ideas and emotions that cannot be explained clearly in words, particularly in subjects of school education such as mathematics, geography, and art. In Taiwan, special education teachers use Braille textbooks to teach blind students. The textbooks contain tactile outline versions of pictures and diagrams. For certain key lines, curves and shapes of these pictures special hand-bonded wires are added, making it suitable for blind students to learn by touch. However, the diversity of these tactile pictures is limited. Teachers who want to supplement the graphics must remove details of the graphics by hand into a simple outline version, and then use a Braille graphic printer to output it. This is quite time-consuming and labor-intensive. Moreover, color information is usually ignored in these tactile outline graphics. In this study, we conducted psychophysical experiments to determine boundaries of the 13 basic color terms. The experimental results were modeled and then used to design a computer app. This application features automatic outline drawing and simplifying the various colors of original pictures into 13 basic colors and convert them into corresponding black and white patterns. The converted black and white pictures can be printed using thermal printers or a Braille graphic printers. This application was tested and evaluated by 8 special education teachers and reported “acceptable” according to the survey using the System Usability Scale (SUS). The teachers also gave advices to improve the computer app.

Keywords: Visual Impairment Education, Tactile, Color

Introduction

1. Background

The training program for blind students in tactile reading and writing is divided into five main parts: preparatory skills for Braille tactile reading, Mandarin Braille, Braille for mathematics and physics (natural sciences and technology), Braille for foreign languages, and Braille for music. These courses mainly focus on the training of Braille conversion of symbols, such as Zhuyin phonetic symbols, English letters, numbers, mathematical symbols, musical notes, etc. The learning method is sequential, requiring students to read gradually from left to right and from top to bottom to understand the content.

In addition to sequential knowledge acquisition, some types of information are presented in graphical form, such as maps, statistical charts, posters, drawings, etc. For individuals with normal vision, this type of information conveyed through shapes, colors, and visual textures is more direct and efficient than verbal descriptions. Therefore, specific tools and equipment have been developed over the years in the field of materials and aids production for the visually impaired, which can replicate embossed patterns or paste specific materials on special paper surfaces, allowing blind students to recognize the shapes and surface textures of images through touch. Examples include Shih plates, track wheels, stereoscopic shape embossers, etc. However, due to the longstanding serious deficiencies in Braille materials and tactile teaching materials, the rights to knowledge of visually impaired individuals have been neglected. In response, the Taipei Blind Parents Association established the Visually Impaired Teaching Materials and Aids Development Center in 1996, to develop a variety of tactile teaching materials so that visually impaired children can have the right to knowledge like sighted individuals.

In order to enable blind individuals to obtain image information including shapes and colors through touch, the author has been constructing a tactile color communication system, or TCCS, since 2013, and has completed initial teaching tests targeting non-blind individuals (Wei, 2013). Subsequently, with the assistance of a research grant from the Ministry of Science and Technology in 2015, the entire system and teaching aids were produced. At the 2016 New York State Association for Education and Rehabilitation of the Blind and Visually Impaired (NYSAER) Conference, it received positive responses from attendants, as well as blind teachers and counselors. It was believed that promoting this system along with Braille teaching could enhance the lives, learning, and reading of blind individuals. However, both at the conference and in blind children's institutions, blind teachers raised concerns about the future development of this system. They pointed out that there are currently no products on the market that use this tactile color communication system for tactile graphic books or aids. Even if blind students learn this system, it would be difficult to apply it in daily life in the short term. In addition, the visually impaired population is a minority, especially in recent years with declining birth rates, making this minority even smaller, reducing the demand. This causes hesitation from manufacturers' interests in developing tactile graphic books and aids. However, the development of teaching materials for the visually impaired should not be constrained by supply and demand considerations, because even if there are only a few visually impaired individuals in our society, they should have the right to "easily access various knowledge."

In the past five years, the author contacted with frontline blind teachers from institutions such as the Taichung HuiMing Blind Children's Nursery and the Hsinchu County Special Education Resource Center, it has been found that professional blind aids and consumables are usually expensive or difficult to obtain. Especially for teachers who travel to different regions for counseling, not every teaching site has the same equipment and teaching aids available. In addition, due to the different needs of visually impaired children, there is often a need to produce and reproduce embossed tactile graphics temporarily. Relying on printing presses for embossing is often not feasible in emergencies, and each graphic requires a separate embossed plate, which is costly. Under such a circumstance, blind students' teachers and parents also need to make their own visually impaired aids. The process is time-consuming and labor-intensive, making them relatively easy to damage.

2. Purpose

In order to improve the shortage of making tactile pictures, a computer application was developed in this study that assists teachers and parents to easily produce tactile pictures for their students and children. This application features automatic outline drawing and simplifying the various colors of original pictures into 13 basic colors and converting them into corresponding black and white patterns as defined in the TCCS. The converted black and white pictures can be printed using thermal printers or Braille graphic printers.

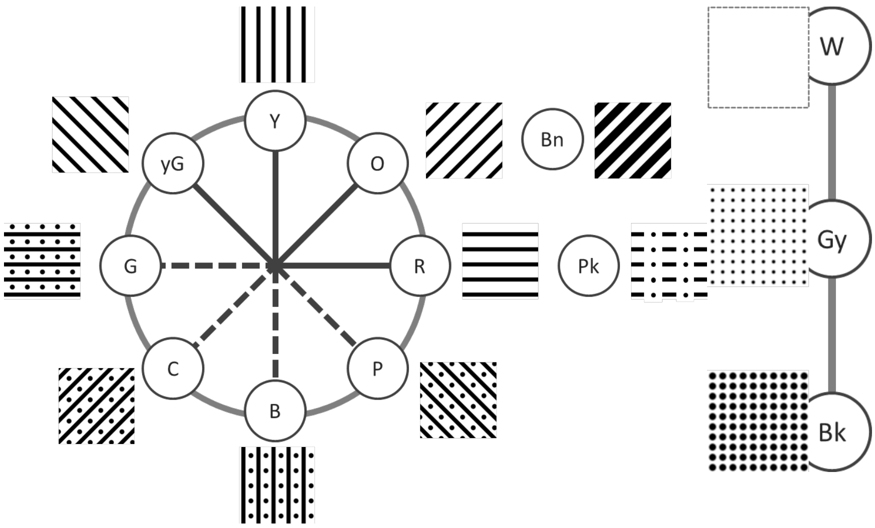
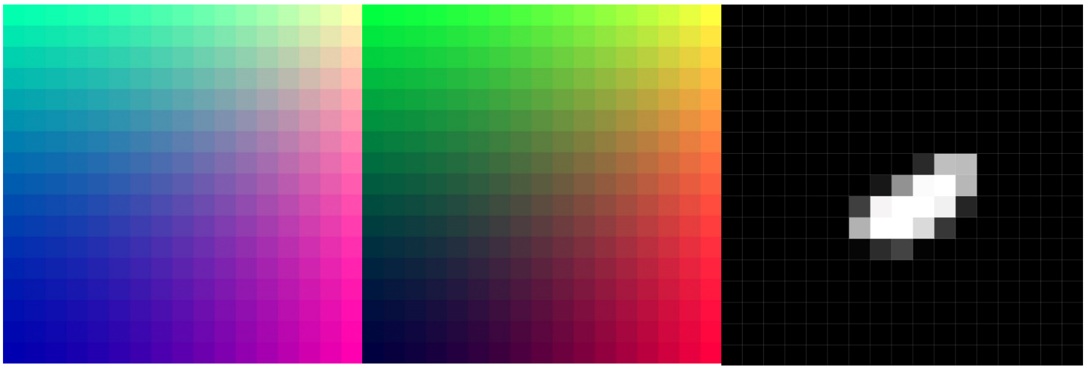


Figure 1: The 13 basic color terms and their corresponding patterns as defined in the tactile color communication system (TCCS)

3. Method

The core of developing the application is to categorize various colors into the 13 basic colors, that is to find out boundaries of the 13 basic colors in a given color space. To do this, a psychophysical experiment was conducted. 48 subjects aged from 18 to 25 participated in the experiment. Before the experiment, the subjects passed the Ishihara color vision test to ensure normal color vision. They were then asked to sit in front of a computer screen and take a 3-minute break to adapt to the experimental environment. In the experiment, the subjects' task was to draw boundaries of given color names on 17 equal-blueness slices of the RGB color cube using Photoshop CS6 (Figure 2(b)). Each slice was composed of 17 by 17 color patches with different R and G values and equal B value. The color patches were arranged sequentially according to their R and G values, as given in Figure 2(a). The color names include red, orange, yellow, yellowish green, green, cyan, blue, purple, pink, brown, white, gray, and black. These are the 13 basic color names people frequently use in daily life to describe colors.



B = 175 B = 63

(a) (b)

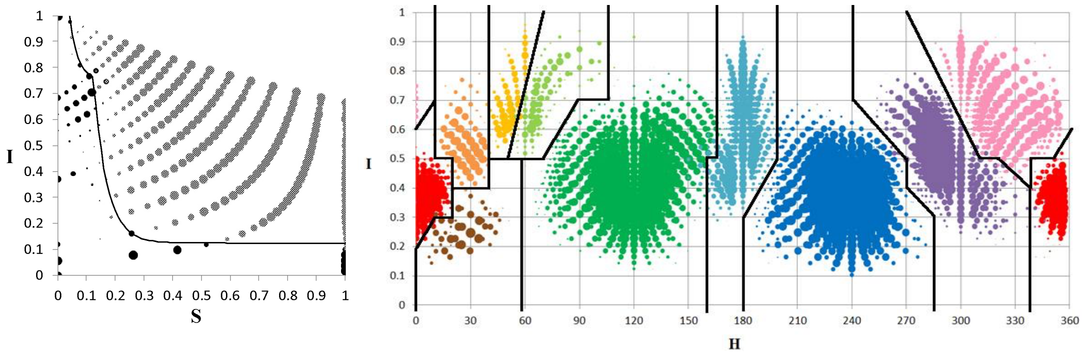
Figure 2: (a) 2 examples of equal-blueness slices of the RGB color cube
(b) the frequency map of "brown" on the slice of B = 63

Conclusion

1. Results

According to the experimental results for each color name, we calculated the frequencies each color patch is circled within the boundary. Fig. 3 shows the distribution of frequencies of the 13 color names on the SHI color space, where S, H, and I stand for saturation, hue, intensity, respectively. The S, H and I values were converted from RGB values.

The experimental results were used to develop a color categorization algorithm, which can categorize 24-bit RGB colors into 13 categories. Each category refers to a basic color name. The black curves and lines in Fig. 3 show the boundaries of the color categories. TCCS is adopted here to convert the 13 color categories into corresponding patterns. Fig. 4 shows test results of the algorithm.



(a) (b)

Figure 3: (a) the distribution of chromatic and achromatic colors on the S-I plane
(b) the distribution of the 13 color names on the H-I plane

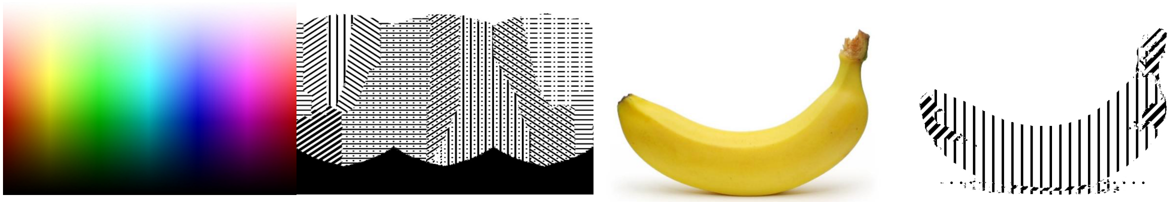


Figure 4: Test results of the color categorization algorithm:
(a) a chart of 24-bit RGB colors; (b) a photographed picture of a banana

2. The Color-Tactile Conversion Application

As shown in Figure 4, the application was developed using C++. The interface consists of a workspace on the right and a series of function buttons on the left. When users load images into the application, they are asked to select one of three paper sizes on which they are going to print out. Afterwards, users can click the "Convert" button to convert the image into the corresponding black and white pattern and outline. For users who want to ignore the black and white pattern, they can uncheck the "Show Pattern" checkbox. The application also provides an eraser function for users to erase unnecessary parts of the picture. After editing the image, users can save and print it. The checkbox "4-Color Mode" allows users to convert various colors into 4 color categories of red, green, yellow, and blue instead of the default 13-color mode.

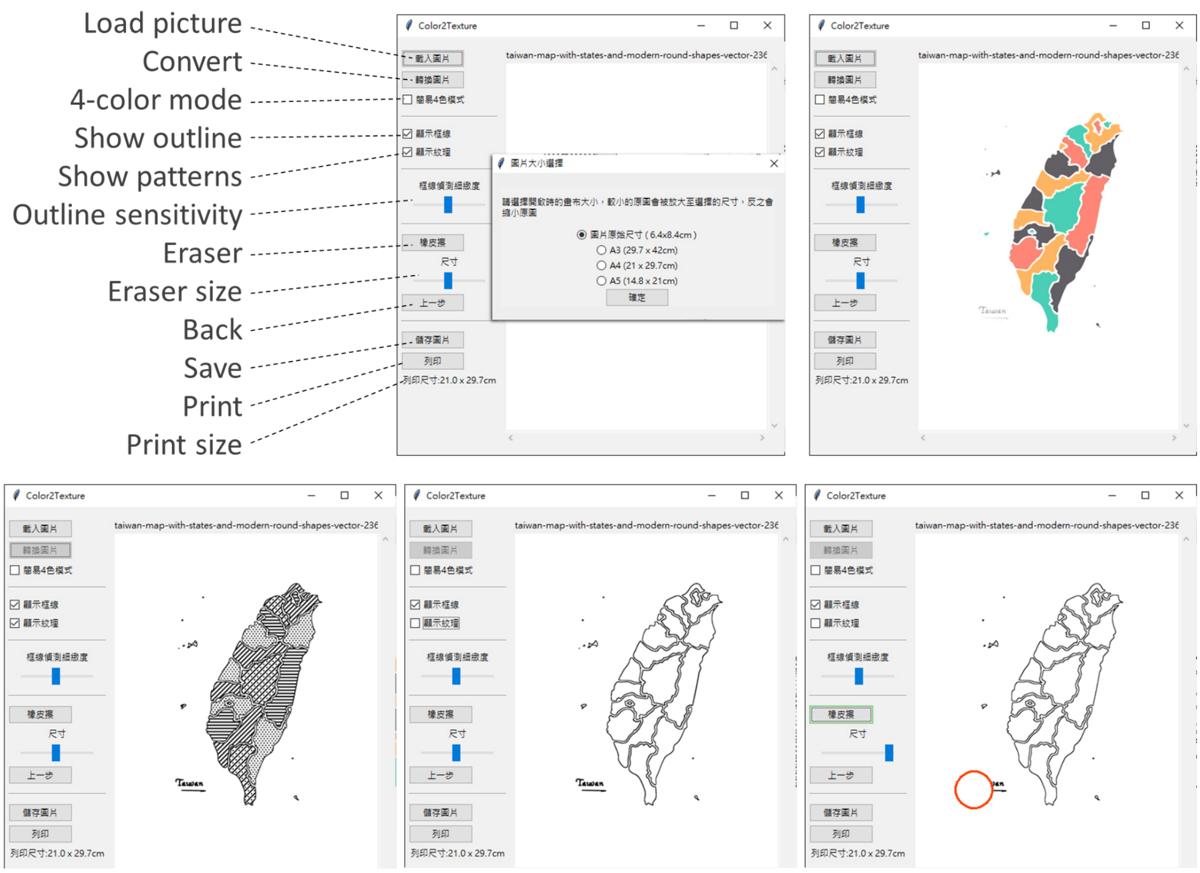


Figure 5: Interface of the Color-Tactile Conversion App

3. Evaluation of the Application

We recruited 8 visually impaired education teachers to use the App and evaluate its usability, ease of use and satisfaction. According to the evaluation of System Usability Scale (Brooke, 1996), the usability scores for the Color-Tactile App ranged from 72.5 to 92.5, which belongs to the acceptable range (Bangor, 2009). The corresponding adjective evaluations are "Good" and "excellent". The results of the questionnaire survey on ease of use, satisfaction, and ease of learning (Lund, 2001) showed a high degree of agreement.

Positive comments given by the teachers include:
1. This computer application can be used in art classes in elementary schools and in grade 7 and above.
2. This can be used to convert graphics for examinations in various subjects for grades 7 and above.
3. Courses that require pictures and diagrams such as geography and mathematics are in great demand.
4. It is a very good tool for the aesthetic education for blind students in primary schools. It can be used to teach them the concept of color scheming for what they are wearing and establish their own image for themselves.

The teachers' suggestions to improve the Color-Tactile App are:
1. This program is very convenient, but outlines and black and white patterns are easily confused for blind students. It is recommended to use different thicknesses to distinguish them.
2. Currently the only modification function is the eraser. It is good to have a black pen tool and a Braille input tool in this application.
3. This computer application is very convenient. If it can work with a Braille graphic printer, the cost of paper supplies will be much lower.
4. In addition to embossing graphics in Braille textbooks, dots and lines of different materials are also manually pasted to increase recognition. If this application is used to create supplementary graphics for class, it is recommended to increase the thickness and convexity of the dots and lines.
5. If this computer application works with a Braille graphics printer, it can be widely used in courses that require graphics such as geography, mathematics, and art.

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