

A Colour Conversion Method Which Allows Colourblind and Normal-Vision People Share Documents with Colour Content

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Abstract

CIE Division 8 currently covers colour imaging for people with normal colour vision. We propose to start a study on how to convert a colour image, especially graphs and letters, into a form that can be viewed by both colourblind as well as normal-vision people, without a sense of discomfort. As a starting point, we will propose a conversion method for colour graphic images and letters. We employed hatching-accumulation on colour area in order to be distinguished by colour blind. The hatching is designed to have specific angle according to the chromaticity on confusion line. The colourblind are expected to distinguish the undistinguished colour by angle. We have tested it with actual colourblind (protanope and deuteranope) using colour graphic and text, and have confirmed that, by adding the hatching pattern, it is distinguished nearly 100%.

1 Introduction

It is known that normal human vision consists of three types of cones, namely L cone, M cone, and S cone. Colourblind people lack one or two cones, or have different characteristics in the spectral sensitivity. Colourblind are usually divided into three categories, protanope, deuteranope, and tritanope, where either the L, M or S cone is missing. Most colourblind people fall into the protanope or deuteranope category where the red and green colours typically are misinterpreted. The percentage of colourblind males is presumed to be from 5% to 8% worldwide.

Colourblind people whose vision consists of two types of cones (dichromat), do not distinguish the colours on the confusion line, which can be drawn on a chromaticity diagram as shown in Fig. 1. The red and green colours on this line, which are difficult for them to distinguish, are clearly distinguished by normal-vision people. These colours are often used to highlight portions of graphs and as well as letters, especially in business communications.

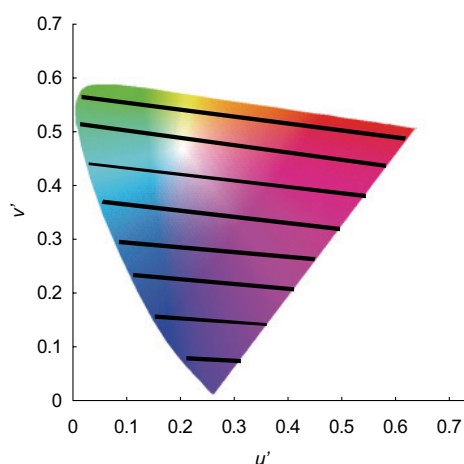


Fig. 1 Confusion lines for deuteranope in the $u'v'$ chromaticity diagram¹⁾.

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green. However, for shapes that are artificially created, the relationship between shape and colour is not obvious, and it is hard to identify the colour.

In visual communication, such as magazines, newspapers and presentation material, colour is often used to highlight or emphasize an object or a subject. For example, the colour red is often used to emphasize important words in a sentence or an important portion of pie chart, bar graph etc. Although such colouring is good for normal-vision people, green and red colours used with charts and/or letters, are hard for colourblind people to distinguish.

To enable colourblind people to distinguish colours, Wakita et al. proposed a method which automatically replaced the original colours in a document with different colours more easily distinguished by the colourblind²⁾. Although it improves visibility for the colourblind, it is not satisfactory for normal-vision people. Ohashi et al. proposed to use arbitrary defined texture to distinguish colours of colour patches and lines, but the texture rule is not simple and is difficult to remember³⁾. Jones proposed a special camera to convert colour patches into textured patches⁴⁾. However, since both lack continuity in texture assignment, viewers are required to remember all explanatory rule one by one.

In this paper, we will propose a simple approach to satisfy both colourblind and normal vision people when viewing content in document that communicates using colour. We applied the approach to figure and text samples and tested the effectiveness.

2 Our approach

To overcome the issue above, we will propose a method to add colour information onto the original document to achieve the following:

- Colourblind people can distinguish the difference between colours,
- Colourblind people can easily identify the colour with a simple legend, and
- Normal-vision people do not have a sense of discomfort.

2.1 Accumulation of hatching

In order to achieve the above criteria, we introduce the following approach; We superimpose a hatching pattern where the angle varies depending on the position on the confusion line, without changing average colour on the original when possible. We use systematically specified hatching angles, determined

on the 'u'v' chromaticity diagram to be from 45 deg. to 135 deg. hatching, to help colourblind people remember colour coordinates as well as more exactly interpret the original colour coordinates. Since the change of angle is continuous, any colour can be depicted. Our approach is to make the original colour as close as possible to the original document colour, allowing colourblind and normal-vision people to communicate with each other using the original colour names. Another benefit of the range of angles is that it will give observers the orientation of the document; i.e., portrait or landscape.

In order to identify the best hatching method, we first performed two preliminary visual experiments with normal visioned subjects⁵⁾. In both tests, nineteen different patches were used. In one test the hatch angle was fixed while the contrast gradually changed from patch to patch. In the second test, both the hatch angle and image contrast gradually changed from patch to patch. These experiments indicated that using hatching with variable angles as a legend resulted in the most accurate results and the hatching patterns could be memorized for a long time as shown in Fig. 2.

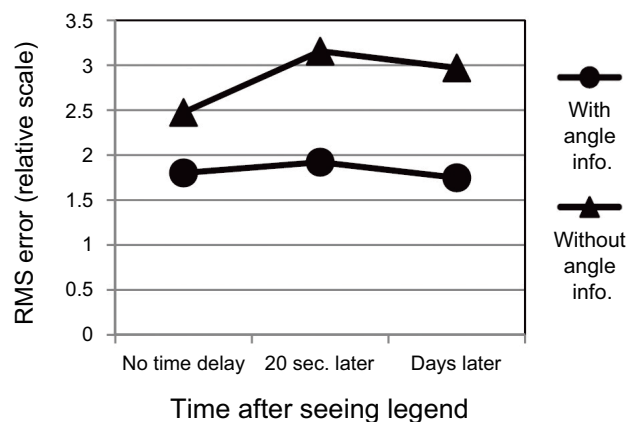


Fig.2 Experimental result in our previous work on memory and its accuracy.

In our previous work, we applied variable contrast of the hatched area depending on the chromaticity on the confusion line. We used low contrast for red and high contrast for green to enable the colourblind to distinguish the colour at a glance. However, as we consider which colour, red or green, should have hatching, we decide to use a symmetric approach: i.e., no hatching contrast at gray and more hatching contrast at saturated colour, so that we can avoid preference issue.

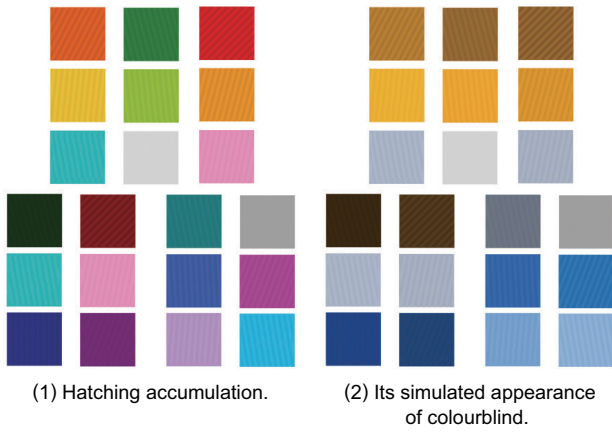


Fig. 3 Example colour patches with hatching and simulated appearance.

2. 2 Determination of hatching angle

We determine the colour angle based on the following criteria:

- The range of hatching angle is within 45 deg. and 135 deg.
- The hatching angle for gray is 90 deg. (i.e., vertical)
- The AdobeRGB and sRGB colour gamut is considered for practical reasons

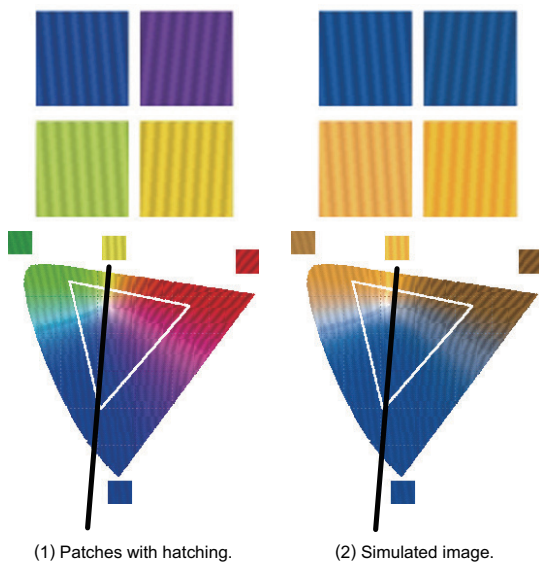


Fig. 4 Determination of hatching angle (The black line indicates 90-deg. hatching).

Since the angle 90 deg. is sensitive to most observers, we carefully chose the colour for it. As mentioned above, we chose gray to be vertical, but we still have some freedom. Through some trial and error, we concluded that observers want to distinguish “blue from purple” and “yellow-green from yellow.” We empirically found that, for those colours, angle should be less than and more than 90 deg. respectively (i.e., left tilt or right tilt).

The Fig. 4 shows examples of blue versus purple and yellow-green versus yellow. We determine the angle in our proposal using the following steps. All calculations are performed in the $u'v'$ chromaticity diagram.

- Step 1: Consider the straight line connecting between the chromaticity of white point (D65) and the blue primary of AdobeRGB and sRGB (Note: They share the same chromaticity for the blue primary). On this line, 90-deg. hatching is accumulated (L90, hereafter).
- Step 2: Define the line parallel with L90 that passes through the red primary of AdobeRGB and sRGB (note: They have the same chromaticity) is determined. On this line, 45-deg. hatching is accumulated (L45, hereafter).
- Step 3: Define the line (L135, hereafter) which is parallel to L90 in the opposite side of L45, and is symmetric about L90.
- Step 4: Determine the angle of an arbitrary chromaticity using proportional calculation.

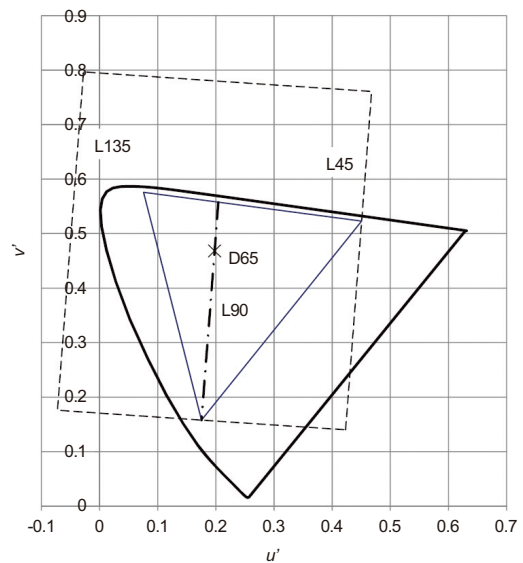


Fig. 5 Determination of hatching angles. (Sign “X” is the white point of D65 and the dotted line through this point indicates the line on which 90-deg. hatching is accumulating. The triangle indicate the colour gamut of AdobeRGB).

The equation (1) indicates its calculation.

$$Angle = \text{sgn}(au' + bv' + c) \cdot A \cdot \frac{|au' + bv' + c|}{\sqrt{a^2 + b^2}} \quad (1)$$

where,

$a = -0,310\ 43$, $b = 0,022\ 392$,

$c = 0,050\ 926$, $A = -4,027\ 4$,

and u' and v' are arbitrary chromaticity.

Fig. 5 illustrates the above definition. The two lines connecting the ends of L45 and L135 that form a square are used for defining sub-hatching described in a later discussion section.

2.2 Adjustment of lightness level

In order to add hatching to the original colour, a margin for dark and light lines are necessary. However, at the edge of a gamut boundary, such room can not be secured. Moreover, we notice that, at the light and dark ends, visibility of hatching tends to be reduced. Thus we have decided to change the average colour only near the gamut boundary by varying the lightness but not the hue. We empirically determine the colours to change through preparative experiments. As a result, we change the following colours: dark green, dark red, yellow, rose, lavender, and light blue. Fig. 6 depicts example of the adjustment.

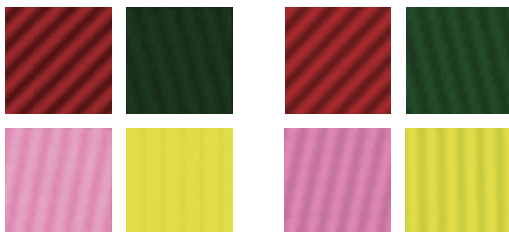


Fig. 6 Lightness adjustment (Left: before adjustment, right: after adjustment).

2.3 Handling of text area

Since a text tends to use narrow lines, we tried three approaches as shown in Fig. 7. One is to add a colour background to the text area, and the other two are to enclose the text area with a rectangular box with some special marks added. In our experiment, we suppose white background.

(1) Hatched background

Hatched background (HB) is designed to extend the idea of hatching accumulation for the text area. The rectangular text area background is filled with the same hue as the text itself but lighter. The rectangular area does not have a border. Hatching is accumulated using the same algorithm as used for figures described above.

(2) Rectangle with angle sign

A background created from a rectangle with a border and with an angle sign (RAS) in one corner is designed to clearly emphasize the colour characters which use the same colour. To distinguish colour, an angle sign is added at the corner depending on

colour. The angle sign is designed to continuously change according to colour.

(3) Rectangle with dotted line

A background created from a rectangle with a border consisting of a solid and a dotted line (RDL) is designed with same idea as above, but, with different mark for the chromaticity. In case of reddish colours, the dotted line appears outside the rectangle and in case of greenish colours, it appears inside the rectangle. This way observers can only distinguish between reddish and greenish.

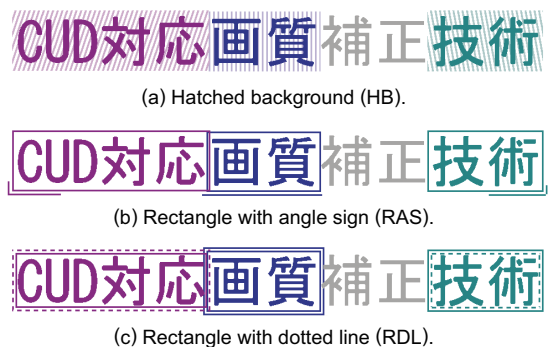


Fig. 7 Three types of marking for text area used in the experiments.

3 Evaluation

Based on what we learned from the first set of experiments, using normal visioned people, we next performed visual experiments.

3.1 Procedure

The general flow of experiment is as follows:

- (1) We explain to the test subjects our objective and method, and have them memorize legends such as the relationship between hatching angles and colours.
- (2) Subjects perform the experiments by identifying patch, colour name and border, and then describing the ease of the judging process.
- (3) We evaluate the result quantitatively and interview the subjects.

3.2 Subjects

Eleven colourblind subjects in total participated: two protanope (P), three protanomalous trichromat (PT), three deuteranope (D) and three deuteranomalous trichromat (DT). A non-profit organization (NPO) for colourblind in Japan helped us to find the test subjects and we identified their colour blindness type based on their declarations.

3.3 Procedure and instruction

Three types of visual experiments are performed using A4 size paper printed by an electronic photography printer. Two of the experiments include the subjects describing ease of judgement. They could select from four levels from “easy” to “difficult.”

(1) Identification of coloured patch and ease of judgement

The chart used to identify the colour patch is shown in Fig. 8. The target colour patch is printed at the left and six coloured patches to be chosen from are printed at the right. A subject is instructed to choose which of the six colour patches matches the colour of the patch on the left patch. Then an easiness level is chosen.

We choose nine sets (pairs and triplets) of colour patches, which have similar appearance for colour-blind, out of 19 colours shown in Fig. 3. Note that two colour patches are overlapped in the figure. The 19 colours are chosen from Microsoft Excel 2003 standard colours which consist of 40 colours. The six colours that the subjects will choose from are selected mainly from the 19 colours and partially from the original 40 colour patches, to have the similar appearance for colourblind. These are evaluated by using VISCHECK⁶⁾.

評価色	サンプル	見分けやすさ
		易 難
		易 難

Fig. 8 Partial view of experimental sheet for patch identification (In the title; left: target colour to evaluate, middle: sample to choose, right: ease of judgement. In the box, left: easy, right: difficult).

(2) Identification of colour name of coloured patch

As shown in Fig. 9, a subject chooses one (in case of a single corresponding colour) or two (in case of an intermediate colour) names out of eight colour names or gray. The eight colour names are printed in Japanese, which are yellow, orange, red, purple, blue, blue-green, green, and yellow-green, in clockwise from the top. Word “gray (black)” is printed at the centre. The subject is allowed to make a mark adjacent to two colour names except for gray if one feels it is an intermediate colour. In case of gray, only gray is allowed to be marked.

We use 23 coloured patches for this experiment. The colours are green, blue, cyan, and yellow in

addition to the 19 colours used above. Note that red and magenta are included in the 19 colours.

図形	色名	
	黄色 橙色 黄緑 灰(黒) 赤色 青緑 青色 紫色	
	黄色 橙色 黄緑 橙色	

Fig. 9 Partial view of experimental sheet for colour name identification (In the title; left: figure, right: colour name).

(3) Determination of border and colour names for coloured text and ease of judgement

As shown in Fig. 10, five Chinese characters are printed with two different colours at left and right. Subject is instructed to mark the border between two different colours. Then, one chooses colour name of left-hand character(s) and right-hand character(s). Only one colour is used in any one character, which the subject is told about beforehand.

A total of 20 pairs of colour combinations are used. Twelve pairs of colour combinations are selected from the 19 colours above. Besides, we add eight colour-and-black combinations, which are commonly used in office documents; i.e., red, green, blue, magenta, cyan, yellow, dark red and light green.

文字 (24pt)	左の文字色	右の文字色	違いの見分け易さ
色文字識別	黄緑 黄色 橙色 緑色 灰(黒) 赤色 青緑 青色 紫色	黄緑 黄色 橙色 緑色 灰(黒) 赤色 青緑 青色 紫色	易 難
色文字識別	黄緑 黄色 橙色 青緑 灰(黒) 赤色	黄緑 黄色 橙色 青緑 灰(黒) 赤色	易 難

Fig. 10 Partial view of experimental sheet for colour border identification (In the title; from left, character in 24pt, text colour at left, text colour at right, ease of judgement).

3.4 Quantization

We quantify the result of our experiments with the following rule.

(1) Identification of coloured patch

Only the right answer is counted as correct, and others are counted as wrong.

(2) Identification of colour name of coloured patch

The right answer is marked either with one colour name (single corresponding colour) or two colour names (intermediate colour). In the experiment, a

subject is allowed to mark one or two colour names. If the answer is correct or the subject's answer has any overlap, we judged it as correct.

(3) Determination of border and colour names for coloured text

Only the right answer is counted as correct, all others are counted as wrong. We apply the same rule for the colour name test.

As for the rating for ease of judgement, we separate easier and more difficult at the centre and indicate in the rating in "easier : more difficult." We leave out the number when the subject put a mark at the centre, so that total number may not be 100%.

4 Result

(1) Identification of colour patch

As shown in Fig. 11, without hatching, the percentage of correct answers ranged from 50% to 90%. By accumulating hatching, it reached to 100%. The rating of ease of judgement increases from 67:10 without hatching to 100:0 with hatching.

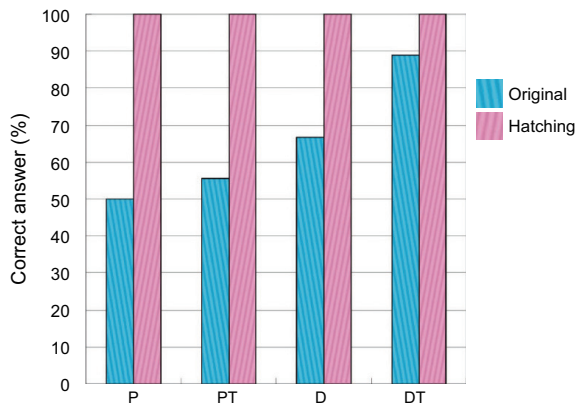


Fig. 11 Identification of colour patch.

(2) Identification of colour name of colour patch

Fig. 12 indicates in case of colour name identification. The percentage increased to 100% with hatching from a range of 75% to 95% without it.

(3) Determination of border and colour names for coloured text

Fig. 13 indicates the result of border test. While the percentage of correct border answer was from 45% to 75% without hatching, BH increases up to around 90%, RAS and RDL increase to 100%.

For the colour naming experiment, all reached nearly 100% from 60% to 90% without any auxiliary means except for RDL as in Fig. 14. The rating of ease of judgement increases from 61:19 to 91:0 by BH, to 100:0 by RAS, and to 97:0 by RDL.

5 Discussions

The results imply that such auxiliary patterns help colourblind to identify colours, and to recognize colour name and colour border. In general, they welcome such information, but some subjects commented

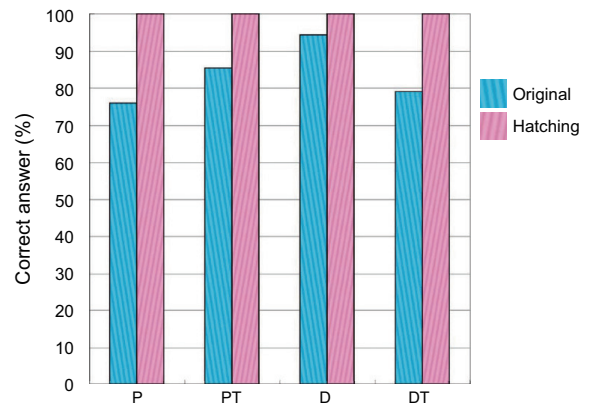


Fig. 12 Identification of colour name.

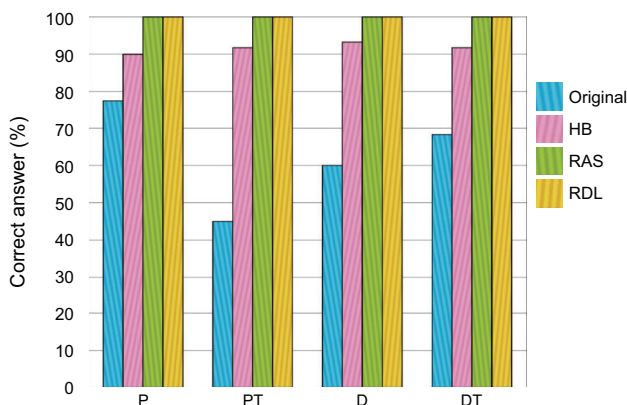


Fig. 13 Determination of border for colours texts.

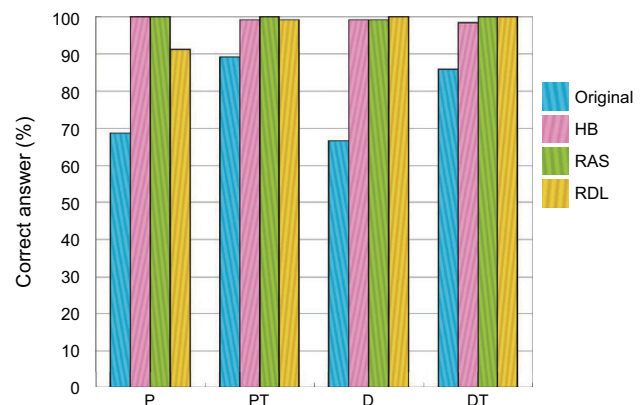


Fig. 14 Determination of border and colour names.

that the hatching gives too much information and tend to be tiring. Some subjects also commented that hatching angles need to be uniquely defined to easily remember the relationship between angle and colour.

From the result and comments, we would need to standardize the angle corresponding to the chromaticity. In this experiment, we set the L90 line to be the line connecting blue primary and the D65 white, but the line connecting unique hues (yellow and blue) may be more reasonable, because normal visioned people are fairly sensitive in that region in terms of colour names. Since the line connecting unique yellow (577nm) and unique blue (472nm)⁷⁾ does not pass through the D65 white, there is a room for discussion.

There may be some discussion of preference in hatching contrast and spatial frequency. In this report, we increase the hatching contrast as the u'v' distance apart from the white increases. Another option will be no contrast at either red or green and highest contrast at the opposite colour. It would be a matter of preference and would be hard to define a unique method.

Hatching frequency should be as visible as possible, but in some cases the hatching texture may interfere with the texture of the original image. To avoid that, the hatching frequency should be high as long as it is recognized by observers. Since functionality is what is important, the method used may not be critical. We think the method used can be selected based on the application.

Regarding the methods for text colour border identification, although there were some differences, they all worked well. We do not have a unique recommendation for which approach was preferred by the subjects – we would need more field tests.

In this report, we consider only trichromat and dichromat. According to the NPO, achromat people are so rare that they can not find such people. These people tend to have another issue such as weak eye sight according to the organization. However theoretically we could add more information with sub-hatching pattern by using the angle from -45 deg. to 45 deg. with different spatial frequency, such as twice the frequency. The approach of determining angles is similar to the one we used in this report. Note that by this method, normal visioned people can identify the colour on a monochrome print as well.

Also, in the actual image, the local colour may not be uniform. In such case, we can define a uniform

angle to a local area so that in that area, the same angle of hatching is accumulated. Fig. 4 is drawn with this approach. Although block artefact may be visible, we can successfully indicate hatching angle on gradation area.

6 Conclusion

We have pointed out the issue of colour communication between normal vision people and colourblind. In order to exchange colour information, we have introduced the approach of hatching accumulation with specified angles depending on the position of the chromaticity on confusion lines. We tested the approach with eleven colourblind subjects. We confirmed that this approach achieves nearly 100% recognition for both figures and texts.

From the experimental result, we have concluded that accumulating hatching texture will significantly help colourblind people understand colour while the average colour stays almost the same – thus both colourblind and normal-vision people can communicate with each other using colour information without a sense of discomfort. We believe that once we define such texturing rules, it will make our society close to barrier-free when it comes to colour communication.

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