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Hiroko Kato
Edith Cowan University

Keng T. Tan
Edith Cowan University

Douglas Chai
Edith Cowan University

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Novel Colour Selection Scheme for 2D Barcode

Hiroko Kato, Keng T Tan and Douglas Chai
Faculty of Computing, Health and Science
Edith Cowan University, Australia
270 JOONDALUP WA 6027 AUSTRALIA
{h.kato | a.tan | d.chai}@ecu.edu.au

Abstract— **The use of colours in 2D barcodes is challenging. This is even more so in barcodes for mobile devices. Although 2D barcodes are fast becoming the ubiquitous tool for mobile computing, most implementations considered monochromatic 2D barcodes. A few colour 2D barcodes are emerging but these implementations only utilises a limited number of colours. In this paper, we present the challenges faced by the use of colours in 2D barcodes for mobile devices. We also introduce a novel colour selection scheme for 2D barcode, which is implemented in our novel colour 2D barcode - the MMCCTM. Our novel selection scheme resulted in a robust 2D barcode that can use more colours than existing colour 2D barcodes for mobile devices.**

I. INTRODUCTION

As camera phones have permeated into our everyday lives, the two dimensional (2D) barcode has attracted researchers and developers as a cost-effective ubiquitous computing tool [1]. A variety of 2D barcodes and their applications have been developed. Nevertheless, they have not been widely used. A possible hindrance is their immaturity in terms of usability and robustness. Increasing data capacity is one of the solutions that addresses both problems since it helps provide a wider variety of applications and improve the robustness using additional data capacity for error detection and correction. One way of achieving this is to use colour symbols for encoding data. However, using a greater multitude of colours introduces problems that can negatively affect the robustness of barcode reading. This is especially true when developing a 2D barcode for mobile devices.

II. CHALLENGES OF A COLOUR ENCODING SCHEME

Despite the potential of using colour to increase the data capacity of barcodes, most researchers/developers prefer to develop monochromatic 2D barcodes. This is because the use of a greater multitude of colours introduces problems that negatively affect the robustness of barcode reading. First of all, colours are more susceptible than their monochromatic counterparts to external effects. For example, a colour image can be reproduced differently from its original colour, depending on the image capturing and processing devices (e.g. scanner, digital camera and web camera) [2], the printing devices used and/or the quality of papers where the image is printed.

Lighting conditions can also have a great impact on the colour value of captured images [2], [3]. In fact, lighting is the primary factor to be considered when using colours. The gamma correction or white balance might be automatically performed by the built-in camera of mobile phones so as to minimise the lighting effect and produce better images. However, what is performed by these cameras is greatly dependent on the Charge Coupled Device (CCD) or Complementary Metal-Oxide Semiconductor (CMOS) sensor used [4].

The factor inherent in colours also has a significant effect on the robustness of barcode reading. A particular colour is often identified within a colour space. Increasing the number of colours to encode data reduces the distance between colours in a given colour space, making it difficult to distinguish each colour robustly. To ensure the robustness of barcode reading, the colours that are furthest apart in a particular colour space are usually selected for encoding data into colour symbols or cells. However, it is inevitable that the use of more colours reduces the distances between the neighbouring colours.

Furthermore, most barcode systems involve more than one colour space in their operation process, resulted in the colour conversion between the different colour spaces. For example, a barcode symbol which is generated using one colour space by hardware such as computers or mobile devices is usually printed with a printer that uses another colour space. It means that two colour spaces have already been used to generate a barcode symbol printed on materials such as paper. The problem is that the colours at a maximum distance one another in one colour space are not necessarily furthest apart in other colour spaces. It is possible for the values of colours originally quite different to become very close after the colour conversion and vice versa, which could result in inaccurate colour discrimination.

The file formats employed for storing the captured images also have a large impact on the fidelity of the reconstructed images including the colour values, due to the compression and decompression algorithms involved in the formatting process. The deterioration of the image fidelity is remarkable especially when lossy image compression algorithm such as Joint Photographic Experts Group (JPEG) is used. In order to develop a colour 2D barcode, we must overcome all the factors that prevent accurate colour discrimination and identification. Before we propose our novel colour selection scheme, we should first look at existing colour 2D barcodes.

III. EXISTING COLOUR 2D BARCODES

At present, three colour 2D barcodes exist: ColorCode, High Capacity Color Barcode (HCCB) and Paper Memory (PM) Code. While ColorCode works as an index 2D barcode, the

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HCCB and PM Code are classified as database 2D barcodes. In 2000, Han et al. invented ColorCode [5], a colour 2D barcode designed for use with inexpensive cameras such as web cameras and mobile phones. ColorCode has overcome the problems in image fidelity by using reference cells that provide the standard colour for correctly distinguishing each reproduced cell. The value of each cell colour in the data area is determined relative to the value of the standard colour in the reference cells. Since the relative difference between the cell colour and the standard colour is consistent, a barcode reader can correctly retrieve the data even when the colour values have changed from their original via the devices used and media where the colour images are printed. The invention of ColorCode demonstrated the feasibility of using colour 2D barcode system, and had a considerable impact on the subsequent colour 2D barcode development.

Despite its potential to improve the data capacity, ColorCode uses colour element merely for eye-catching symbol design (see Fig. 1 (left)). On the other hand, both HCCB and PM Code have been developed to improve the data capacity within a given symbol space, by encoding colour symbols. The HCCB can achieve at least three times the density of industry standard 2D barcodes such as PDF417 or Data Matrix within the given space by encoding colour symbols into a triangular cell set (see Fig. 1 (right)), which takes up less space than square cells [6]. HCCB succeeded in improving its data capacity by not only increasing the number of colour symbols but also reducing the cell size.

PM Code [7] uses a unique layered structure to improve data capacity within a given available symbol space significantly (see Fig. 2). A PM Code symbol is made up of a plurality of layers with each consisting of a 2D matrix barcode. The cells in particular colour combination comprise each layer. The colour of each cell in the surface layer may present the colour of a single code layer or the resultant colour from adding the plurality of code layers. When the resultant colour is identical to the colour used in one of the layers, the resultant colour will be converted to a designated colour according to the PM Code colour conversion algorithm that involves two colour spaces: the RGB (i.e., Red, Green and Blue) colour space and the HSB (hue, saturation, brightness) colour space. The PM Code colour conversion algorithm, together with its index information code included in the surface layer, enables the decoding software to detect the presence or absence of colour cells in each layer, which in turn enables the successful read of each code layer, resulting in a successful decode of the entire PM Code.

Fig. 1 Examples of ColorCode (left) and HCCB (right).

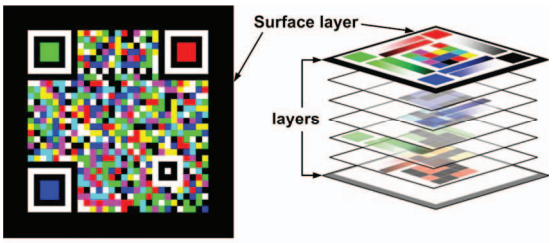

Fig. 2 PM Code layer structure.

Both HCCB and PM Code have been proposed as maximal 2D barcodes in terms of data capacity for a given symbol space. However, when used with resource-limited camera phones, these colour 2D barcodes allow only a limited set of colours, such as 4 (or the maximum of 8 colours) because neither of them was specifically designed for mobile devices. This prevents them from being used as a robust ubiquitous computing tool. The number of colours to encode data must be increased in order to achieve the data capacity required for a ubiquitous computing tool. Furthermore, all the colours must be robustly identified and retrieved even when camera phones are used as an image processing device. Thus, herein we propose a novel colour selection scheme for 2D barcode.

IV. Colour Selection Scheme for Robust Encoding

The most challenging task through the entire barcode development was selection of colours used for encoding data. As previously identified, there are four major factors that have negative effects in retrieving colour values:

i. colours are reproduced differently depending on the display and/or printing devices and media where they are printed;
ii. lighting effect;
iii. colour conversion performed in the barcode encoding and/or decoding process; and
iv. file format to save the captured image data.

The first problem can be solved by using colour reference cells, following the ColorCode's approach. As a solution for the lighting issue, the thresholding techniques such as adaptive thresholding have demonstrated their strong capability in minimising the light effect even when the target images were unevenly lit [8] (see Fig. 3).

However, it has been revealed that the values of some colours have changed, including those in colour reference cells. For this experiment [8], which addressed the effect of the adaptive thresholding on the colour images captured by a built-in camera of mobile phone, the eight colours that are furthest apart one another in the RGB colour space (i.e., red, green, blue, cyan, magenta, yellow, white and black) were used. However, the values of some colours such as " red and magenta " and " blue and cyan " have become quite similar, resulting in the incorrect colour identification through the adaptive thresholding.

This indicates that some colour values/information have either lost or changed via colour conversion involved in the barcode encoding/decoding process. A barcode system usually

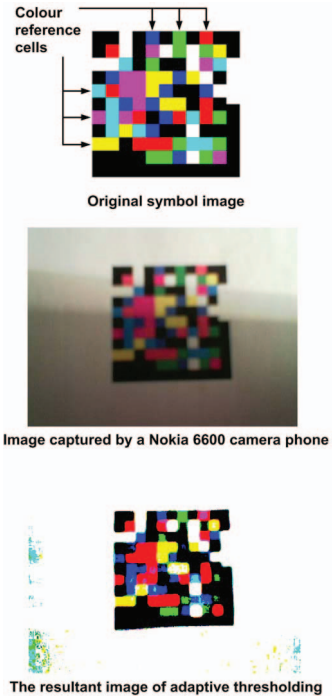

Fig. 3 Effect of the adaptive thresholding.

involves more than one colour space, for instance, RGB colour space for generating a barcode symbol and CMYK colour space for printing it. It is known that the colour gamut (i.e., a range of colour a device can produce) produced by RGB monitors is wider than the gamut achieved by colour printing devices that use CMYK colour data. Hence, the printing devices cannot reproduce the colours that are within the gamut of RGB monitors but outside the colour printing gamut. This prevents the accurate colour conversion between RGB and CMYK spaces.

Furthermore, the file format used for saving image data affects the accuracy in the colour values of reproduced images. This is especially true when the JPEG file format is used. Most photographic image capturing devices including camera phones use JPEG file format.

This led us to the conclusion that, in order to develop a robust colour 2D barcode system, we need to select colours that can preserve the maximum distance between their neighbouring colours across all the colour spaces involved in the barcode operating process and furthermore, through the lossy compression/decompression.

The question then is how to select these colours. It has been found that not all of the eight colours that are furthest apart in RGB space remain as they were after the colour conversion and data compression/decompression. In order to preserve the initial distance, some of the colours should be removed, which limits the number of colour symbols that can be used for robustly encoding and decoding data, resulting in less data density for a given symbol space. From our experiments, we observed that slight inaccuracy or trivial information loss in 3D colour space may result in a considerable change in colour values as compared to 2D space, when converting colours from one colour space to another and/or compressing or decompressing the colour data.

As a solution, we attempted to select colours on a 2D space or a plane of the RGB colour cube, making the colour conversion between the planes of each colour space, instead of 3D to 3D conversion. Prior to the colour selection, we examined the susceptibility of each of the 8 colours at the vertices of RGB colour cube (i.e., red (R), green (G), blue (B), cyan (C), magenta (M), yellow (Y), black (K) and white (W)) towards the external effects such as colour conversion and data compression/decompression [8]. The experiment results indicated that:

i. The set of colour values of K is consistent showing the least susceptibility to the external effects while three colours, B, C and M are more susceptible than other colours.
ii. The set of RGB values of M is quite similar to those of R. Similarly, the colour values of C are quite close to those of both B and G.
iii. When comparing the 3 primary colours (i.e., R, G and B), R is least and B is most susceptible to the external effects.

As a result, we have selected a plane KRWC (i.e., the plane which has KRWC at its 4 corners), and 9 points on the plane, whose values equal to the values of the colour symbols to encode data. These are “0,0,0,” “0.5,0,0,” “1,0,0,” “0,0.5,0.5,” “0.5,0.5,0.5,” “1,0.5,0.5,” “0,1,1,” “0.5,1,1” and “1,1,1,” in the normalised RGB colour range [0, 1], each representing black, brown, red, dark green, grey, tan, cyan, sky blue and white. In addition to these 9 colours, yellow “1,1,0” is selected as a colour symbol, resulting in 10 colour symbols available for encoding data (see Fig. 4). This is because the colour values of yellow demonstrated its insusceptibility to any operations applied throughout the colour selection process [8].

The values in YCbCr colour space outside the RGB colour space are considered to be invalid and will be processed so as to generate valid RGB value during the colour conversion process. The 10 colours of YCbCr space in Fig. 4 are within the valid RGB value, yet preserving the maximum distance apart within the valid limit. This visually demonstrates that the 10 colours are furthest apart across more than one colour space, RGB and YCbCr colour spaces in this case. The clear separation of the colour symbols, which is enabled by this novel colour selection scheme, help improve the robustness in reading colour 2D barcodes even when using resource-limited camera phones as an image processing device.

V. Implementation and Testing of Our Scheme

We have implemented our novel colour selection scheme in a colour 2D barcode called Mobile Multi-Colour Composite (MMCC™) [8]. This novel barcode was tested from two different perspectives:

i. an overall performance of MMCC™ using 100 sample symbols (1st experiment); and
ii. its effectiveness and robustness in different conditions, and under a variety of scenarios (2nd experiment).

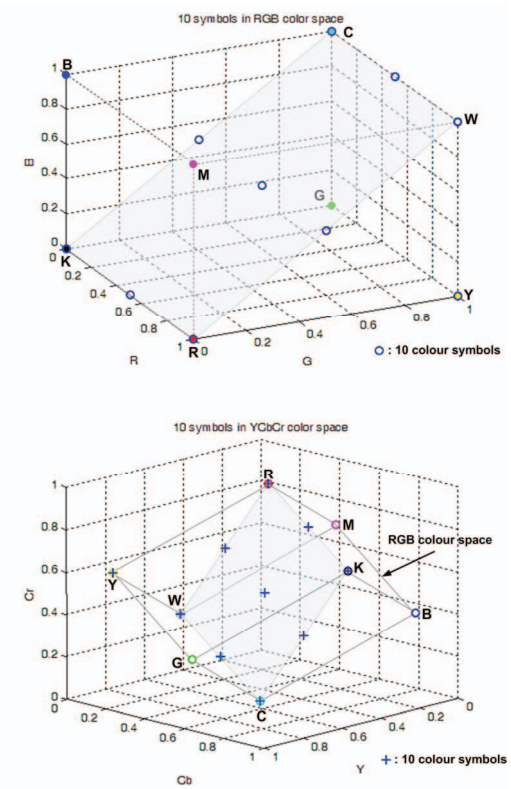

Fig. 4 10 colours represented in RGB color space (top) and the same 10 colours represented in YCbCr colour space (bottom).

In the 1st experiment, the first read rate (FRR) of each sampled symbols have been analysed, where

$$FRR = \frac{Number\ of\ successful\ first\ reads}{Number\ of\ attempted\ first\ reads}.$$

This metric measures the reading reliability of the MMCC™ barcode. The 2nd experiment examined the robustness of the MMCC™ barcode. A legible symbol in a certain condition or under a certain effect indicates that the barcode is tolerant of that type of condition or effect. Hence, either "legible" or "illegible" is used as a metric in the 2nd experiment.

Each sample for the 1st experiment contained 165 bytes of alphanumeric characters (without compression) in 30 × 30 data cells, in the symbol size of 5.5 × 5.0 cm^2. The data capacity of the sample symbols (error correction rate of 22%) were nearly 4 times the maximum data capacity of industry standard database 2D barcodes (e.g., QR Code and Data Matrix) for a given symbol size. The FRRs of the MMCC™ were 100% in all three different camera resolutions (i.e., QVGA, VGA and 1.3 megapixels) used for capturing the sample barcodes. In the 2nd experiment, different types of defective symbols were created by tearing, making holes or drawing a line across the symbol. Some samples were tested under the different light conditions. Throughout the 2nd experiment, the MMCC™ barcode has demonstrated remarkable capability in terms of reading robustness and tolerance to the different types of physical damages and lighting conditions. Fig. 5 presents some examples of MMCC™ barcode symbols that were legible.

While currently available colour database 2D barcodes such

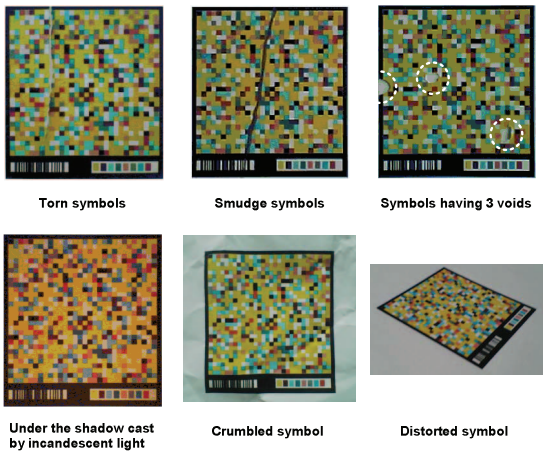

Fig. 5. Examples of tested symbols.

as HCCB and PM Code use a maximum of eight colours, our novel colour selection scheme allowed the use of ten colours to encode data in a MMCC™ barcode. The experiments showed the improvement in data capacity as well as the robustness of our novel colour selection scheme.

VI. Conclusion

In this paper, we have presented problems of using colours in 2D barcodes. This is a common problem for the few existing colour 2D barcodes. As a solution, we have proposed a novel colour selection scheme that overcomes some of the challenges encountered in using more colours for 2D barcodes. Our novel scheme has resulted in the design of a novel colour 2D barcode, which is a robust and fault tolerant barcode using more colours than any existing colour 2D barcode for mobile devices.

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