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Adaptive use of thresholding and multiple colour space representation to improve classification of MMCC barcode

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ADAPTIVE USE OF THRESHOLDING AND MULTIPLE COLOUR SPACE REPRESENTATION TO IMPROVE CLASSIFICATION OF MMCC BARCODE

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Fig. 1: An example of MMCC barcode

Fig. 2: Effect of lighting on colour value

ABSTRACT

Colour 2D barcodes, such as the MMCC barcode, have been developed recently to improve the data capacity of monochrome barcodes. However, the use of colour imposes greater challenges in decoding the symbols correctly as different lighting conditions on the barcode vary the values of the colours significantly. Hence, it is desirable to have an adaptive classification of the data cells so as to adapt to various lighting conditions. In this paper, we propose a classification method that is able to adapt to different lighting conditions during the classification of the MMCC data cells in a mobile environment. To highlight the effectiveness of this method, it is compared against the classification of the data cells performed in two different colour space representations, namely RGB and YCbCr.

Index Terms— 2D Barcode, Ubiquitous Computing

1. INTRODUCTION

Over the last few years, colour two-dimensional (2D) barcodes have been developed to cater for higher data capacity. One such colour 2D barcode is the Mobile Multi-Colour Composite (MMCC) barcode developed at Edith Cowan University. An example of the MMCC barcode is shown in Fig. 1.

With the use of an increased number of colours, colour 2D barcodes are able to achieve higher theoretical data capacity than the equivalent monochrome types. However, the effect of lighting on colour is often inconsistent [1]. Hence, accurate representation of the colour becomes challenging. As shown in Fig. 2, the white paper was captured using a mobile phone camera under white fluorescent lighting with the left hand side of the paper under shade. This created a shadow on the left hand side of the paper and resulted in lower RGB values for the shaded pixels as compared to those pixels that were under direct lighting. This highlights that different lighting intensities significantly affect the RGB values of the pixels.

Images captured by mobile phone cameras are most commonly saved in the Joint Photographic Experts Group (JPEG) format. This format uses a lossy compression [2] which is intended to significantly reduce the file size by reducing the image quality in the precision of chromatic information [3].
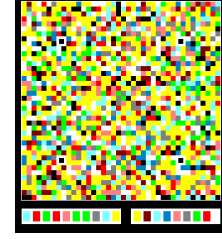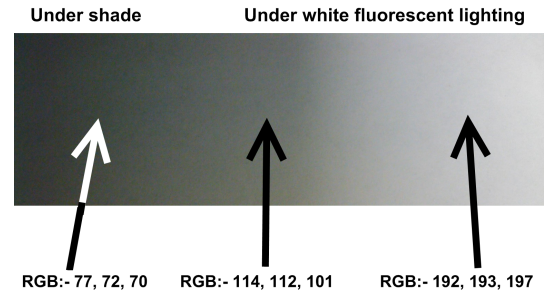
This is achieved by first transforming the image into a colour space model that is able to separate the luminance from the chromatic information, and then performing sub-sampling of the chromatic information. One such colour space model is the YCbCr colour space representation which will be discussed further in Section 2. The JPEG artifacts that arise due to the lossy compression make accurate reading of the data cells even more challenging.

In this paper, we present a method to improve the accurate reading of the MMCC data cells in the mobile environment by classifying the data cells in the YCbCr colour space representation, with a different weighting given to the luminance information based on the overall brightness of the image captured. To highlight the effectiveness of this method, it is compared against the classification of the data cells performed in both RGB and unweighted YCbCr colour space representations. In addition, we also propose the adaptive use of multiple colour space representation to further improve the classification of the data cells.

This paper is organised as follows:

- A brief introduction of MMCC barcode and the use of colours to increase data capacity of the barcode was provided in this Section.

- In Section 2, various colour space representations for image are discussed.

- Section 3 provided an anatomy of the MMCC barcode.

- Methods used in this paper to determine the threshold values and closest reference colour are discussed in Section 4.

- In Section 5, the proposed method used to improve classification of the data cells is highlighted.

- Experimental results and observations are presented in this Section.

- Conclusions can be found in Section 7.

2. COLOUR SPACE REPRESENTATION

Colour images can be represented in various colour spaces such as RGB, YCbCr, NTSC, HSV, HSI and CMYK colour spaces. In this paper, we have chosen the RGB and YCbCr colour space representations as RGB colour space representation is one of the most commonly used colour space for images while YCbCr is used in JPEG images.

RGB colour space representation uses the additive primary colours (i.e. Red, Green and Blue) to represent different colours [4]. The primary colours represent the basic hues which can be added to produce other colours.

The YCbCr colour space is commonly used in digital video and JPEG images. In this colour space representation, the luminance information (i.e. represented by Y) is separated from the chromatic information (i.e. Cb and Cr) [5]. The YCbCr values can be obtained from RGB using the following equations [6]:

$$Y = 0.257R + 0.504G + 0.098B + 16 \tag{1}$$

$$Cb = -0.148R - 0.291G + 0.439B + 128 \tag{2}$$

$$Cr = 0.439R - 0.368G - 0.071B + 128 \tag{3}$$

where R, G and B are the 8-bit unsigned values of the three primary colours in the RGB colour space representation. During the conversion, Y has a nominal range of 16 to 235 while Cb and Cr have values ranging from 16 to 240.

3. ANATOMY OF MMCC

As shown in Fig. 3, the structure of the MMCC barcode [7] has four main parts: finder pattern, reference colours, header and data cells.
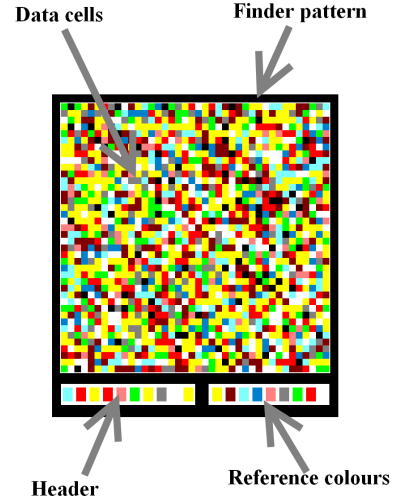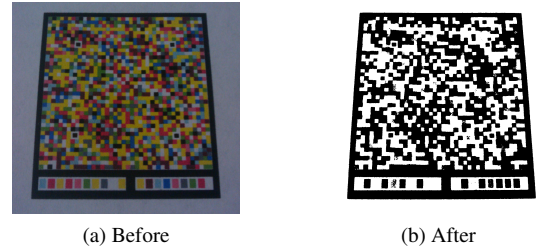

Fig. 3: The structure of the MMCC barcode

(a) Before (b) After

Fig. 4: Image of the MMCC barcode before and after thresholding

3.1. Finder pattern

The finder pattern facilitates the MMCC barcode to be located easily. Usually, the image of the barcode will be thresholded before the decoder attempts to find the barcode.

Thresholding of the images involves a decision making process whereby a pixel is determined to be either black or white. Usually, when the pixel's value is higher than the threshold value, it will be set to one and zero when its value is lower than the threshold. After thresholding, we have a binary image as illustrated in Fig. 4b.

3.2. Reference colours

During encoding of the colour 2D barcode, RGB values of the symbols are determined and encoded. However, when it is captured from printed media, the captured values tend to shift away from these original ones [8]. Together with lighting effects on colour that are often inconsistent, correctly classifying the data cells becomes challenging.

Unlike other colour 2D barcodes, MMCC uses reference colours with the aim to resolve the above challenges. As an example, as highlighted in Fig. 5, the location of the captured data cell (i.e. 148, 155, 165 in 8-bit unsigned RGB
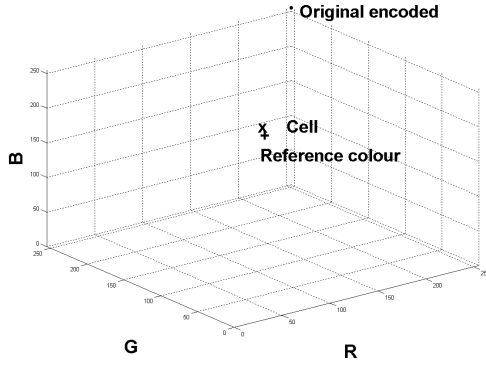
Fig. 5: Locations of one of the original symbols encoded, reference colour and data cell captured

colour space representation) is closer to the reference colour (i.e. 143, 145, 161) than the original encoded location (i.e. 255, 255, 255).

By comparing the data cells to the reference colours, instead of comparing to the original encoded values, it provides a means for the colours to calibrate themselves to both the lighting conditions and to the movement of colour values arising due to images being captured from printed media. This greatly improves the robustness of the barcode. However, the use of reference colours to decode the data cells correctly is not fault-proof as the amount of light illuminating on one part of the barcode may not be similar to another part.

3.3. Header

The header of the MMCC barcode contains information about the barcode, such as number of data cells, error correction ability and interleaver's seed which can act as a key to unlock the barcode. The header can either be a traditional one dimensional (1D) barcode that contains bars and spaces or a colour barcode as shown in Fig. 3.

3.4. Data cells

The data cells contain both the data and error correction parity bits of the barcode. The more data cells there are, the higher the data capacity becomes.

4. DETERMINING THRESHOLD VALUES AND CLOSEST REFERENCE COLOUR USED

In this section, two processes of the decoding are discussed in greater detail. One of them is the algorithm used to determine the threshold values for converting the colour images to binary while the other process is the classification of the data cells.

4.1. Determining the threshold values

Thresholding of the images requires a decision making process whereby a pixel is determined to be either black or white. Usually, when the pixel's value is higher than the threshold value, it will be set to white, and black when its value is lower than the threshold.

In this paper, the threshold value is determined based on the overall brightness of the captured image. The brightness of any pixel can be computed from (1) while the threshold value is determined based on:

$$Y_{TH} = \frac{\min(Y_i) + \max(Y_i)}{2} \quad (4)$$

where $i = 1, 2, 3, ...N$ is the pixel that is being sampled and Y is the luminance component of the pixel.

Using the threshold value, the binary image as shown in Fig. 4b can be constructed based on

$$G_i(R, G, B) = \begin{cases} 1 & if \ Y_i \geq Y_{TH} \\ 0 & otherwise \end{cases} \quad (5)$$

where $i = 1, 2, 3...N$ is the pixel's position and Y_i is the luminance component of the pixel.

4.2. Classification of the data cells

In the encoding process, the location and RGB values of each of the reference colours is determined. When decoding the barcode, the values of the data cells are then compared against values of the reference colours. The symbol that each data cell represents is determined based on the closest distance to the reference colour. In RGB colour space representation, the minimum Euclidean distance (ED) between the data cells and the reference colours is determined based on

$$ED = min\big(\sqrt{(R_i - R_j)^2 + (G_i - G_j)^2 + (B_i - B_j)^2}\,\big) \quad (6)$$

where i and j are the data cell and reference colour number of the barcode respectively, while R, G and B are the RGB values of the respective data cells/reference colours.

If the minimum Euclidean distances are computed in the YCbCr colour space, the computation will be

$$ED = min\big(\sqrt{(Y_i - Y_j)^2 + (Cb_i - Cb_j)^2 + (Cr_i - Cr_j)^2}\,\big) \quad (7)$$

where i and j are the data cell and reference colour number of the barcode respectively, while Y, Cb and Cr are the luminance and chromatic values of the respective data cells/reference colours.

5. PROPOSED METHOD

This paper proposes a method to improve the accurate decoding of the data cells. In this method, the data cells are classified in the YCbCr colour space representation, with a different weighting provided to the luminance information based

on the overall brightness of the image captured. Here, this is referred to as method 3. To illustrate the effectiveness of this method, it is compared against the classification of the data cells performed in both RGB and unweighted YCbCr colour space representations, which are referred to as method 1 and 2 respectively. In addition, this paper also proposes the adaptive use of multiple colour spaces to further increase the accurate reading of the data cells.

5.1. Classification of cells in methods 1, 2 and 3

In method 1, the classification of the data cells are computed based on the nearest reference colour in the RGB colour space, where as method 2 is performed in an unweighted YCbCr colour space. As the mobile MMCC decoder is operating on a mobile phone, which is a computationally limited platform, the classification of the data cells is altered. Instead of computing the Euclidean distance based on the root mean square (RMS) of the differences between the data cells and reference colours, the mean square is used to reduce computation resources.

The modified equations (8) and (9) are used, which we refer to as methods 1 and 2 respectively, for classification of the data cells.

$$D_1 = min\big((R_i - R_j)^2 + (G_i - G_j)^2 + (B_i - B_j)^2\big) \tag{8}$$

$$D_2 = min\big((Y_i - Y_j)^2 + (Cb_i - Cb_j)^2 + (Cr_i - Cr_j)^2\big) \tag{9}$$

whereby i and j are the data cell and reference colour number of the barcode respectively. R, G and B are the primary colours of the respective data cells/reference colours in the RGB colour space while Y, Cb and Cr are the luminance and chromatic information in the YCbCr colour space representation.

As for method 3, a different weighting is applied for the luminance information based on the brightness of the captured images. The classification of the data cells is then performed in YCbCr colour space. Using the threshold value (i.e. Y_{TH}) that is computed in (4), a luminance adjustment factor, Y_{adj} is derived.

The data cells are classified based on the distance computed as described in (10).

$$D_3 = min\big(Y_{adj} \times (Y_i - Y_j)^2 + (Cb_i - Cb_j)^2 + (Cr_i - Cr_j)^2\big) \tag{10}$$

Based on our study, the values of the luminance adjustment factor, Y_{adj}, that are used according to the threshold values, Y_{TH}, are presented in Table 1.

5.2. Adaptive use of multiple colour space representations

During the decoding of colour 2D barcodes, unlike in most communication protocols such as TCP/IP, the mobile decoder

Table 1: Values of Y_{adj} based on Y_{TH}

Threshold value, Y_{TH}	Luminance adjustment factor, Y_{adj}
$V_{TH} \leq 97$	0.45
$97 < V_{TH} \leq 100$	0.30
$100 < V_{TH} \leq 103$	0.25
$103 < V_{TH} \leq 106$	0.20
$106 < V_{TH}$	0.15

Table 2: MMCC symbols and RGB values (8-bits unsigned)

Symbol Representing	Red	Green	Blue
0	255	255	0
1	255	255	255
2	127	255	255
3	0	255	0
4	255	127	127
5	127	127	127
6	0	127	204
7	255	0	0
8	127	0	0
9	0	0	0

will not be able to request the encoder to reprint/re-transmit the barcodes in the event when there are errors, especially when the barcodes are supposed to store all the data within themselves. Therefore, there is a need for the code to have error correction ability built in.

One commonly used error correction scheme is the Reed Solomon coding, which allows the decoder to determine the received code in various statuses such as

- No errors detected,

- Errors detected and able to correct the errors, or

- Errors detected but not able to correct the errors.

Out of the three statuses, only "no errors detected" and "errors detected and able to correct the errors" are desirable. Using these statuses, the decoder are able to implement an adaptive selection of the colour space for classification of the data cells.

6. EXPERIMENTAL RESULTS AND OBSERVATIONS

This paper uses a 40 by 40 data cells MMCC barcode that is generated from MATLAB. The encoded barcode is then printed on white paper with physical dimensions of 30 mm (width) by 33.75 mm (height). Within this barcode, ten different colours are used and their RGB values are listed in Table 2. The colour 2D barcode is presented in Fig. 6.
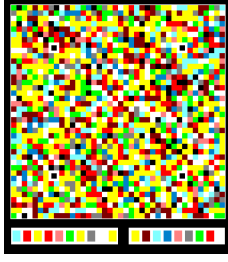
Fig. 6: MMCC barcode used in this paper

6.1. Lighting conditions and decoder used

The MMCC mobile decoder is developed using Microsoft Visual Studio .NET Compact Framework environment with C#. This decoder is operating on an HTC Touch Diamond, a Windows Mobile 6.1 phone, with a 3.2 Mega pixel camera. The MMCC barcode is captured under the following lighting conditions:

- White fluorescent lighting that is commonly found in offices,

- Outdoors on a mostly cloudy day, and

- Outdoors on a clear sunny day.

These represent three typical lighting conditions whereby colour 2D barcodes are commonly read with a mobile phone camera. In each lighting condition, 30 samples of the MMCC barcodes are captured.

The settings of the decoder's camera are listed as follow:

- Auto-focus activated

- Resolution set to "3M"

- White Balance set to "Auto"

- Brightness set to 0

- Quality set to "Super Fine"

In order to remain consistent in the results, the influence of shadows on the barcode are kept to the minimum. This is achieved by capturing the images with the author standing behind the barcode with the light source at his front, so that no shadow is cast on the captured images.

6.2. Results and observations

In Table 3, the statistical values of Y_{TH} for all the MMCC images captured under different lighting conditions are shown.

Examples of those images captured under white fluorescent lighting, outdoors on a mostly cloudy day and outdoors on a clear sunny day are illustrated in Fig. 7.

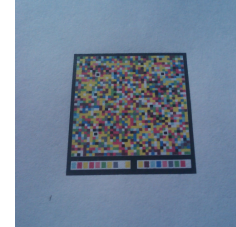**Table 3**: Statistical values of Y_{TH} based on different lightning conditions

Lighting conditions	Yth			
	Min	Max	Mean	Medium
White fluorescent lighting	94.25	106.18	100.56	100.78
Outdoor on a mostly cloudy day	94.16	104.83	99.57	99.21
Outdoor on a clear sunny day	100.83	114.84	105.65	106.07
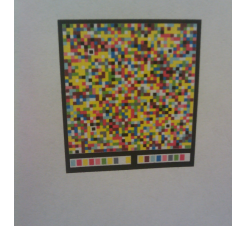
(a) under white fluorescent lighting
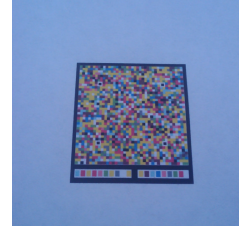
(b) Outdoors on a mostly cloudy day

(c) Outdoors on a clear sunny day

Fig. 7: MMCC barcode captured under different lighting conditions

We observed that the threshold values, Y_{TH}, computed from (4) do not vary significantly under the different lighting conditions that are tested. This is most likely due to the "Auto" white balance setting that allows the camera to automatically adjust itself to different lighting conditions during the capturing of images [9].

6.3. Performance of methods 1, 2 and 3

Based on the samples captured, the percentage of errors arising from wrong classification of the data cells are listed in Table 4.

As the ten chosen colours are designed for use in the mobile environment under normal office lighting conditions (i.e. under white fluorescent lighting) [7], the number of errors obtained are significantly lower when operating in such conditions as compared to both outdoor conditions.

Classification performed in methods 1 and 2 are desirable when the barcodes are captured under normal light conditions, as methods 1 and 2 outperform method 3 by about

Table 4: Percentage of errors in classification of the data cells

Lighting conditions	Method		
	1	2	3
White fluorescent lighting	0.43%	0.58%	0.78%
Outdoor on a mostly cloudy day	2.62%	3.15%	1.37%
Outdoor on a clear sunny day	8.39%	9.64%	3.38%
Average	3.81%	4.46%	1.84%

Table 5: Block of data (eight bytes) classified using method 1 and 3

ASCII decimal	Method 3	Method 1
80	80	80
83	83	83
79	79	79
72	42	41
53	53	53
90	90	90
92	82	92
126	116	116

0.28% in this lighting condition. However, when the colour barcodes are captured in both types of outdoor lighting conditions, the number of errors for methods 1 and 2 are much higher than in method 3. In outdoors on a clear sunny day, method 3 significantly improves the robustness of the MMCC barcode by about 5.6%. Overall, method 3 reduces the errors by about 2.3% as compared to the other two methods.

Although the YCbCr colour space representation allows separation of luminance and chromatic information, it is noted that the classification purely based on unweighted colour space (i.e. method 2) is worse off as compared to classification in the RGB colour space (i.e. method 1) in all three lighting conditions.

6.4. Performance of the adaptive use of multiple colour space representations

As method 3 has the best performance among the three methods, it is therefore used as a default method to classify the data cells. However, when the amount of errors are greater than the Reed Solomon error correction ability, the decoder will then use the next best method (i.e method 1) to classify the data cells.

As an example, Table 5 presents a block of data (i.e. eight bytes of data and Reed Solomon parity) from one of the MMCC barcodes captured outdoors under a clear sunny day. With the ability to correct only two error bytes, method 3 is unable to correct the errors whereas method 1 is able to.

Therefore, adopting an adaptive classification which allows the best colour space to be used for each data block can further improve the robustness of the barcode.

7. CONCLUSIONS

Here, we have shown that lighting conditions on barcodes can affect the performance significantly. Hence, it is important to have an adaptive decoding method that is capable of adapting to various lighting conditions. Our adaptive classification of the data cells in method 3 has shown to improve the robustness of the barcode by reducing the amount of errors by more than 50% as compared to classification in both RGB and unweighted YCbCr colour space. Also, we have presented the adaptive use of multiple colour space representations to further improve the robustness of the MMCC barcode. In future, more lighting conditions and classifications based in different colour spaces will be studied.

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