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A Fuzzy Multi-Layer Color QR Code Decoder Algorithm

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ABSTRACT

In this paper, we proposed a multi-layer QR code decoder algorithm to recognize the colour of an extended QR code. The extended QR code enhanced the locator pattern, a component in the QR code to provide more colours. The algorithm starts with the detection of the QR code, followed by selecting colour reference from the extended QR code. Then, dynamic fuzzy sets from colour values are produced for each colour using colour reference from the QR code. QR code colour enhancement is then implemented based on fuzzy set decision. Next is colour de-multiplexing for the enhanced colour QR code, to get monochrome QR code by decoding the extended QR code. We obtain the original file and compare our decoder with existing decoder in terms of the success rate. The experiment shows a success rate of 80% recognition and detection from computer screen, 34% better compared to previous work. Furthermore, 70% recognition and detection is produced from printed paper, 44.27% better compared to previous work.

Key words : fuzzy, colour QR code, decoder, success rate, algorithm.

1. INTRODUCTION

QR code is a popular type of 2D-barcode. Nowadays, we can see QR code anywhere, for example in the store front, bus ticket, business card, posters, business advertisements, etc. The drawback of current QR code is its limited size. To increase the file size encoded within QR code, many researches proposed colour QR code [3], [4], [6].

The size of the QR code can be increased, by adding multiple colour layers. Colour multiplexing is applied to the colour layers and produced colour QR code with data capacity equal to QR code size multiply by number of colour layers. Adding colour to QR code create more challenge in the decoding process. The decoder needs to deal with noise that exists in the monochrome QR code. The noise is from colour illumination and colour format for printed paper and colour illumination from the computer screen [6], [7]. Until now, there have not exist any colour QR code decoder to recognize both, QR code from computer screen and QR code form printed paper. This is due to the change of colour format from Red, Green and Blue (RGB) colours on computer screen and Cyan, Magenta, Yellow and BlacK (CMYK) on printed paper. Fuzzy is a powerful technique utilized to recognize images such as bacteria [21] and skin colour [25]. Due to these facts, has motivated us to produce a fuzzy decoder that can recognize extended colours in QR code on computer screen and printed paper.

This paper consists of six sections. Section 2 explains about QR code. Section 3 reviews the related research works. Section 4 gives a concise explanation on the encoder to produce the extended QR code. Section 5 is the proposed QR code decoder. Section 6 discusses the experiments and finally section 7 is the conclusion and future works.

2. QR CODE

2.1 Black and White (B/W) QR Code

Black and white QR code has different version form version 1 to 40. The data size that each version can encode depends on the data type and error correction level. There are four types of error correction, each level can fix certain percentage of damage [1, 2] in the QR code as follows:

[L] - Low up to 7% damage
[M] - Medium up to 15% damage
[Q] – Quality up to 25% damage
[H] – High up to 30% damage

Table 1. Black and white QR code data size.

Symbol size	Min. 21x21 cell - Max. 177x177 cell (with 4-cells interval)	
Maximum Data Size (version 40)	Data bits	10,208
	Numeric	3,057
	Alphanumeric	1,852
	Binary	1,273
	Kanji	784
Error	Level L	Up to 7%

correction	Level M	Up to 15%
	Level Q	Up to 25%
	Level H	Up to 30%

Error correction comes at a cost, the higher the error correction the lower data to be encoded. Table 1 show the data size summary where black and white QR code can encode.

2.2 Color QR Code

To overcome the size limitation for black and white QR code, colour layers are added [22], [19]. [6] which means, the colour QR code data size is equal to the number of layered color QR code. The calculation is as follows:

Number of colours used for colour QR code = the number of QR code layers * B/W QR code data size

The data size is calculated using the following formula:
Colour QR code data size = log2N [2] * D.
Where, N is the number of colours, and D is the data size of B/W QR code.
Figure 1 show an example of a colour QR code.

Figure 1: Color QR code

3. RELATED RESEARCH WORK

We will describe in detail three systems that we are using as our benchmarks in our research work as follows:

3.1 Research Work by Zhibo Yang, 2016 [22]

They proposed a fast decoding for high density colour QR code. The receiver will first make a localization and geometric transformation, then colour recovery using the colour reference in the identification pattern, to get enhance colour QR code. Colour decoding produced three monochrome QR code. Finally, the resulting QR code will be decoded to get the original file. Figure 2 shows the decoder process. From our review, this research provides colour recovery using machine learning. However, using this technique cost more time to decode the QR code.

3.2 Research Work by Blasinski, Henryk, 2013 [19]

They proposed a colour barcode framework by exploiting the spectral diversity afforded by the Cyan (C), Magenta (M) and Yellow (Y) print colour channels commonly used for colour printing. The receiver captures data from the printed paper then use Kubelka-Munk theory to get the colour value. The printed pattern is formed by the overlay of layers printed with C, M and Y on the paper using substrate light incident technique. The printed colour QR code is transmitted through the successive colourant layers, reflected by the paper substrate and then transmitted again through the colourant layers as it returns. Figure 3 shows the colour layer process.

Figure 3: Color Layers [19]

From our review, this research provides good data capacity with acceptable success rate for printed QR code. However, their algorithm cannot work for the QR code from computer screen.

3.3 Research Work by Thilo Fath, Falk Schubert,and Harald Haas, 2014 [6]

Authors have proposed data transmission within an aircraft cabinet. The data is transferred by stream of QR code. The QR code are captured by built-in camera of passenger's mobile camera and are decoded to reconstruct the transmitted data. The receiver captures the QR codes from a mobile camera. The captured visual codes are visually decoded. The visually decoded data packets are reassembled in the correct order by means of additionally encoded meta-information providing the packet number. Then, the encoded data is decoded. Finally, the decoded data is decrypted and uncompressed and the reconstructed file is stored on the user device. The sending and receiving process is shown in Figure 4. From our review, this system provides good data capacity with good success rate for QR code on computer screen. However, their algorithm cannot work for the QR code from printed paper.

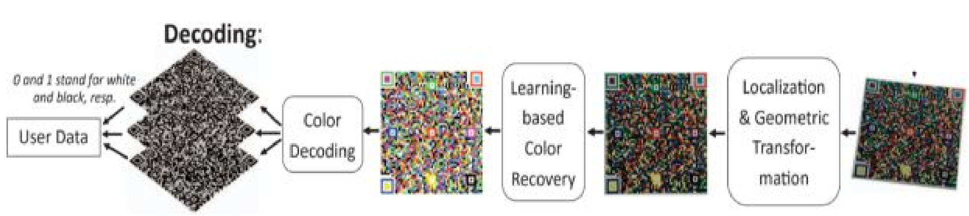

Figure 2: Decoder Process [3]

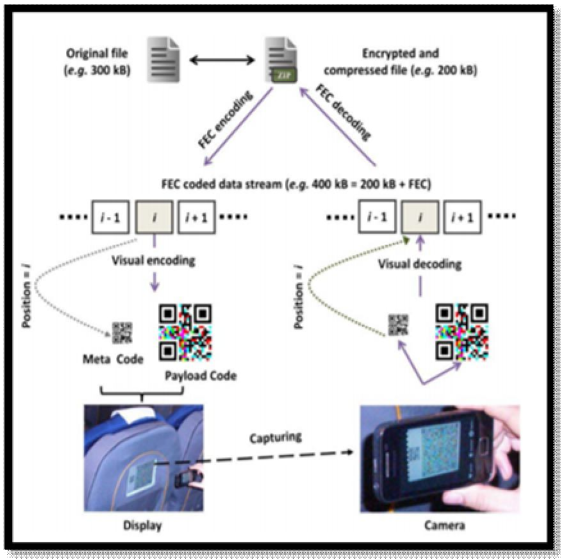

Figure 4: IFE Screen [6]

3.4 Comparison between Existing Systems

We compare the systems in five aspects consisting of: (a) the camera (b) captured from either computer screen or printed paper (c) number of colours (d) success rate and (e) algorithm used as shown in Table 2. From Table 2, the best success rate produced is 46% for QR code captured from computer screen and 25.73% for QR code captured from printed paper.

4. COLOUR QR CODE ENCODER

The encoder QR code algorithm is as follows:

i. First the user inserts the max size in paper and its data to encode.
ii. Our algorithm will check the max size on paper and select the best fit black and white QR code for that space using fuzzy technique.
iii. Select the number of chucks = data size / max size for the selected QR code.
iv. Number of colours = 2^ number of chunks.
v. Generate black and white QR code for each data chunk and give each chunk a specific color.
vi. Merge all generated QR code into one colour QR code.
vii. Replace the identification pattern with colour reference identification pattern.

Our proposed encoder, which produced the extended QR code, a larger QR code size compared to previous work is shown in Figure 5. However, this paper focus on the decoder.

Table 2: Comparison between Existing Systems

Research Works	Camera Megapixel	Capture from	Number of Colour	Success Rate	Algorithm Used
(Zhibo Yang , 2016)[22]	8M	Screen	8	46%	Color reference
(Blasinski, Henryk,2013)[19]	5M	Printed paper	8	25.73%	Diffuse reflection
(Thilo Fath, Falk Schubert,and Harald Haas, 2014)[6]	5M	Screen	8	40%	Color multiplexing

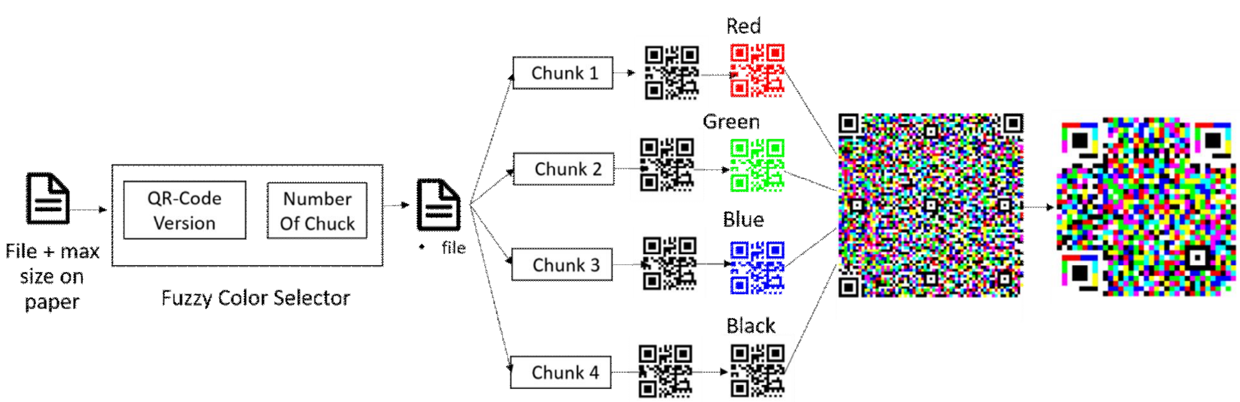

Figure 5: Proposed Color QR Code Encoder

5. QR CODE ENCODER

Our proposed QR code decoder algorithm is as follows:

i. Detect the Colour QR code then make Localization & Geometric Distortion Correction to get QR code with its original rotation.
ii. Select the reference colour from identification pattern we will have three identification reference for reach colour.
iii. Build fuzzy set for each identification colour base on its reference as described in section 5.1
iv. Return all the colours in the detected QR code to its origin base on the fuzzy sets from step 3
v. Split the Colour QR code to monochrome QR code.
vi. Decode the monochrome QR codes.
vii. Merge the decoding result to get the original data

The proposed decoder is shown in Figure 6.

5.1 Fuzzy Colour Selection

The proposed system has four inputs, each input for a specific colour layer. Figure 7 is an overview of the proposed fuzzy process. The triangular function is selected, from the encoded QR code because there is lower and upper limit for the colours. The colour value for each colour layer will be either 0 or 255. Therefore, for the receiver we need to return each colour its original value. A threshold value of 127.5 is used but in some cases because of brightness or darkness using this threshold will give incorrect result. Therefore, the triangular function with three heads, namely Dark, Average and Light as shown in Figure 8, was selected to determine the appropriate value for the colour

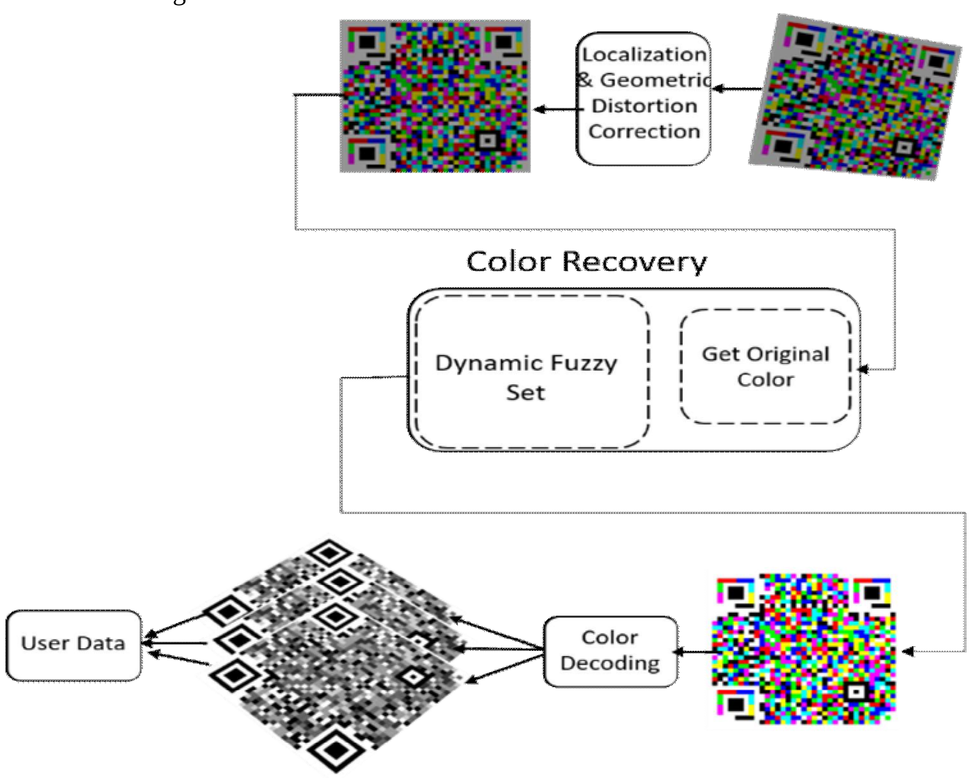

Figure 6: Proposed Colour QR Code Decoder

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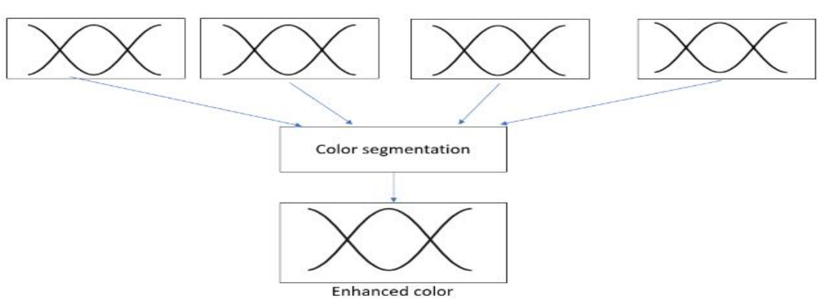


Figure 7: Proposed Fuzzy Process

5.2 Fuzzification

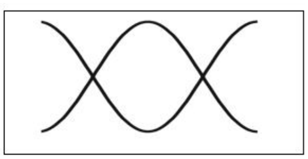
MAX operator is used for the fuzzification process. The MAX operator is used to select the colour value, which are dark, average, light. For example, if the colour value was X, (0 to 255) we select Rdark, Raverage and Rlight (R represent red colour) using the membership functions that will be explained in section 5.3 and the maximum value will be the colour value.

5.3 Membership Function

The characteristics for colour input is the colour component which starts from 0 until 255. The lowest value belongs to darker colour and the heights value lighter colour. The median between colour references will be considered as the average value. This field can be divided into three membership functions Dark, Average and Light. Triangular functions were selected as mentioned in section 5.1.

The average value (x) is calculated from the average red value from colour reference e.g if the red colour reference value 200, 220, 170. So the X for red colour will be 196
Figure 8 shows the three membership functions for colour component which consists of:

- Minimum: 0.
- Maximum: 225.
- Average: X.
- Colour (Dark, Average, Light).



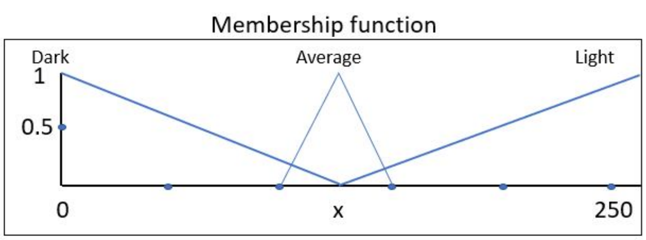


Figure 8: Membership Function for colour component.

5.4 Fuzzy Rule

In this system the decisions made for the colour component will either be 0 or 255. In the proposed system, three fuzzy rules are used 3 times for each colour component, red, green and blue. The fuzzy decisions output for each colour will be either min for 0 colour value or max for 255 colour value. The rules will check the output from the membership function for each colour which is (light, average, dark) and base on the member ship function result will issue the colour value. The fuzzy role is as follows:

if (colour is light) then
  colour value is max // max value is 255
else if (colour is average) and (other colour value is dark) then
  colour value is max
else colour is value is min // min is 0

5.5 Defuzzification

For this function, we get enhanced colour value based on the fuzzy result. For the defuzzification process we get the result from the fuzzy rules in section 5.4 for each colour component. The generated colour will be the mix for all colour component result with the maximum of 16 possible colours, which must be the same as the sender of the QR code.

6. RESULT AND DISCUSSION

For evaluation, we test our system using datasets consisting of 10 printed QR code on paper and 10 QR code from computer screen total 20 QR code. We capture the QR codes using Iphone6 and calculate the success rate for each colour layer. The success rate of printed QR code is shown in Table 3 and Figure 9. We also calculate the success rate for QR code read from computer screen and the result is shown in Table 4 and Figure 10.

Table 3: Results from Printed Paper

	Success Rate
Red	80%
Green	70%
Blue	70%

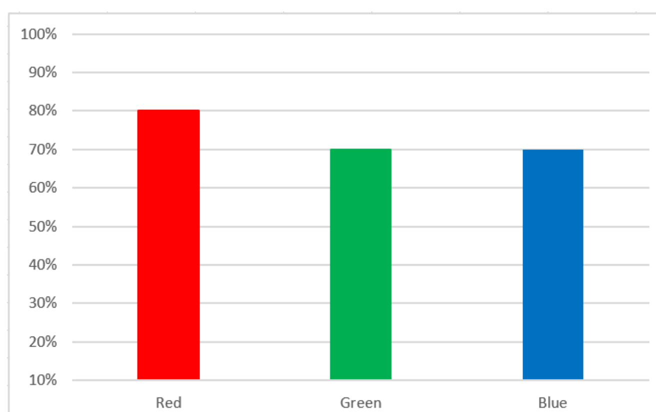


Figure 9: Results from Printed Paper

Table 4: Results from Computer Screen

	Success Rate
Red	90%
Green	80%
Blue	80%

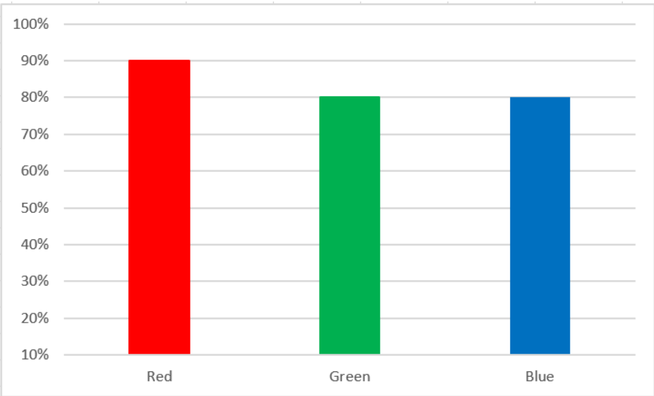


Figure 10: Results from Computer Screen

7. CONCLUSION AND FUTURE WORKS

In this paper, we show our proposed decoder algorithm for a four-layer colour QR code utilizing fuzzy technique. The result shows that using fuzzy, we can decode colour QR code on both printed paper and computer screen. For future works, the system will be tested for the decoder success rate with more dataset, multiple light conditions on both printed paper and on computer screen.

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