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EVALUATION OF A FUZZY 3D COLOR QR CODE DECODER

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ABSTRACT

This paper is an extension of our previous work on color QR code decoder using fuzzy logic. The input is the color QR codes with four versions which are version 3, 13, 14 and 17. These QR code versions are converted to black and white. Then, the QR codes are detected using an open source library named as Zing. Next, the color QR code is retrieved by mapping the black and white QR code with the color image. This is followed by enhancing the color QR code using fuzzy logic. After that the QR code is split into three QR codes, red, green and blue. Each of the color is decoded to get the original file text file. **We made a comparison on the success rate for our decoder with other existing decoder.** We take in consideration number of color used, camera resolution, QR code version, and QR code error correction level. The comparison with other research work show that by using fuzzy logic improves the decoding success rate up to 93.33% using the same parameter from other research work.

Keywords *Fuzzy, QR code, QR code version, Color QR code, Decoder*

1. INTRODUCTION

QR code convert any type of digital data into transferable images consisting of thousands of bits per image, which can be displayed on the screen or printed, and then captured by smartphone camera to recover the information [1, 2, 3]. Due of this feature QR codes are being used everywhere in marketing and network security applications such as business cards, storefront displays, letter stamps, movie posters, shortcuts to URL links, information tracking products, a means to store contact information for easy transfer, admission tickets or boarding passes, etc. [1, 3, 4, 5, 6]. QR code is a special type of 2D barcode. QR code has many features like 360 degree rotation, error correction, and larger data capacity that can be encoded within it [1, 4, 7, 8]. QR code can hold data size up to 10 times higher than normal barcode. However, there is also limitation of QR code. Since the maximum data size for black and white (B/W) QR code is 10208 bits [1, 4, 5], the QR code is unable to encode simple files like PDF files, Word documents, PowerPoint slide show. Having QR-Code with larger capacity will facilitate many modern applications and make transferring data easier. Many research works have been implemented to overcome the size limitation and color lamination for QR code using various techniques such as diffuse reflection [19], color reference [22] and colour multiplexing with metadata [6]. In this paper, we compare the success rate for these techniques with the success rate using our proposed fuzzy technique.

This paper consists of 7 sections. Section 2 is about color QR code. Section 3 explains barcodes types. Section 4 provides facts on the benefits of having larger QR code size. Section 5 reviews the related research works. Section 6 discusses on the results of the experiments and finally section 7 is the conclusion and future works.

2. COLOR QR CODE

The data size of QR-Code can be increased by adding colors [1, 5, 7]. Colors in QR code can be obtained by encoding different layers of monochrome QR codes and merge it to one colored QR code, in other words the data size of colored QR code is equal to the number of QR code layers multiply by B/W QR code data size. The data size is calculated using the following formula:

Color QR-Code data size= log2N [2] * D

Where, N is the number of colors, and D is the data size of B/W QR-Code.
Color QR code can hold more data, but decoding is the challenging part. This is due to the fact that the data decoder should work with many types of noisy data such as color illumination, brightness, and blur. Due to noisy data the best decoding success rate for 3 layers of color QR code can reach up to 80% [5, 7]. In our previous work, we have implemented fuzzy logic color QR code decoder and the result show that the success rate can reach up to 100% for camera 20 Megapixel (MP) [1]. Figure 1 shows an example of color QR code which is proposed in our previous work. In this paper, we will show an overview of what are the benefits of using QR code with larger data capacity and we will show comparation results between our previous work and other researchers' works.

Figure 1: Color QR Code

3. BARCODES TYPES

3.1 1D Barcode

1D Barcode or traditional barcode normally represent data instead of storing the data inside it. It can represent 10-20 alphanumeric while the reader read this representation and send to database to get the information. In other words, it represents the key for the database record. Figure 2 shows a sample of this type of barcode. [9, 17]

Figure 2: 1-D Barcode

3.2 2D Barcode and QR code

It is the new version of 1D barcodes. The main feature for these barcodes is it can store data in 2 dimensions vertical and horizontal which means larger data capacity than 1D barcode. The second key feature of 2D barcode is easy to read in other words only mobile apps needed to decode those barcodes, while in 1D Barcode need special reader to read and get the information. There are many types of 2D barcodes and we will show an overview for the most famous 2D barcodes.

3.2.1 Data matrix

Data matrix is two-dimensional matrix code, which use a visual representation of binary code (0 or 1). It is applied for encoding large amount of data characters, for example marking very small containers, in pharmaceutical industry for unit dose and product marking. It is originally developed for tracking millions of parts in large factories. Data matrix code is shown in Table 1(A).

3.2.2 Maxi code

Maxi code is developed and used by UPS (United Parcel Service) on packing slips for package tracking and address sorting world-wide. It is made up of offset rows of hexagonal modules arranged around a unique finder pattern. Maxi code is shown in Table 1(B).

3.2.3 QR code

QR code was invented in 1994 by the Japanese company Denso Wave. It gains popularity due to its key features: larger data capacity, error correction, and error correction. Now it is used in many applications such as marketing and network security applications, business cards, storefront displays, letter stamps, movie posters, shortcuts to URL links, information tracking products, admission tickets or boarding passes, etc. QR-Code is shown in Table 1(C).

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3.2.4 Code block F

Code block F is a 2D bar code developed by ELMICRON, as an extension of 1D Barcode. Within its capacities, it is possible to cut a given 1D Barcode into several pieces and to arrange them in a multi-row symbol. It is used for small labels and secure data while part of the code is used as a security layer. Code block F is shown in Table 1(D).

3.2.5 Aztec code

Aztec code is a 2D bar code. It can encode small to large amounts of data with user-selected percentages of error correction. The code size adjusts automatically depending on the amount of input data. Aztec code is shown in Table 1(E).

Table 1 summarizes the comparison between popular 2D barcodes.

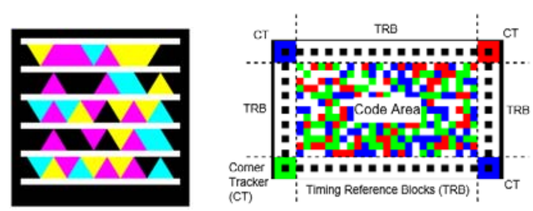
Table 1: 2D-Barcodes

	2D-Barcode	Capacity	Rotation Support
A	Data Matrix	1556 ASCII (8 Bit), 2335 alphanumerical or 3116 numeric characters	360 Degree
B	Maxi Code	93 ASCII characters	N/A
C	QR-Code	4296 Alpha, 7089 Numeric characters	360 Degree
D	Code Block F	up to 2725 ASCII or 5450 numeric characters	N/A
E	Aztec Code	3067 alphanumeric, 3832 numeric, 1914 Bytes	360 Degree

3.3 3D Barcode

3D Barcode it is special type of 2D Barcode. When color is added it become the third dimension. 3D barcode main feature is larger data capacity compared to 2D barcode.

There are a few types of color barcodes. The most famous one is High Capacity Color Barcodes (HCCB). It has been developed by Microsoft team and the main propose is applied in Microsoft mobile tagging. HCCB barcode use colored triangles to encode the data. Maximum data capacity for HCCB code is 3,500 characters and 8 colors is used in this barcode. Figure 3(a) shows the HCCB barcode. The other types of 3D barcodes is not been widely used because it still needs improvement, such as COBRA barcode which has been developed to extend the capacity of 2D barcode. The maximum data capacity for COBRA barcode is 18.8K bits, and 5 colors used to achieve this capacity Figure 3(b) shows the COBRA barcode.



(a) (b)

Figure 3: Example of 3D-Barcode (a) HCCB (b) COBRA

Color QR code researchers are trying to increase the size of 2D barcode by multiplexing different layers of monochrome QR code. The maximum data size is 3 times bigger than ordinary QR code. By using 8 colors, Figure 4 illustrates the way to implement color multiplexing for color QR code.

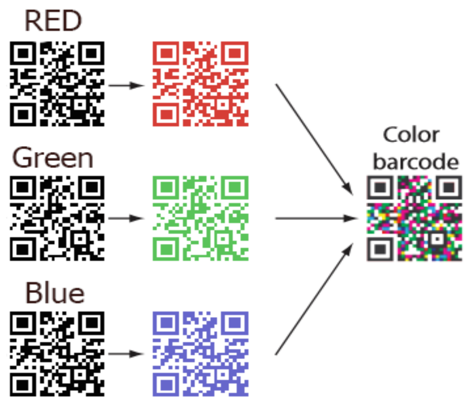


Figure 4: Example of Color QR Code Multiplexing

4. BENEFITS OF ENCODING LARGER DATA WITHIN THE BARCODES

Many researches develop solution using QR code. One of the limitations of QR code is small data size capacity. Researchers are finding solution to overcome these limitations using special application attached to database or using multiple QR code. Table 2 shows the different aspect of using QR code and the benefit of using QR code with larger capacity.

Table 2: Uses of QR Code

Research Work	Used Location	QR Code Size Limitation and Suggested Improvement
(Thilo Fath, 2014)	Airplane	Using multiple QR codes to send the full file. It can be improved by using one large QR code.
(Yu-Cheng Lin, 2014)	Maintenance management system	Store the maintenance ID in QR code and attach this ID to the internet URL. It can be improved by storing the full history in the QR code.
(A. Łutkowski, 2014)	Location navigation indoor building	Store QR code information to tell whether, room is closed or open for blind people. If QR code size is large the QR code can store the room scheduler information to help the blind people.
(Jih-Fu Tu, 2015)	Room lock	Store only user mobile ID to unlock the room. Store user profile will be better.
(Hsin-Chih Lai, 2013)	Out-door learning	Store ID of trees and attached to URL. Improvement can be done by storing trees information in the QR code.

5. RELATED RESEARCH WORKS

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

5.1 Research Work by Sin Rong Toh, Weihan Goh and Chai Kiat Yeo, 2016

This research work proposes new way to exchange data between mobile devices using color QR code stream.

The sender in their work is color multiplexing to generate color QR code. First, the file is split into equal chunks and each chunk will be the color QR code, then this color QR code is displayed as video stream.

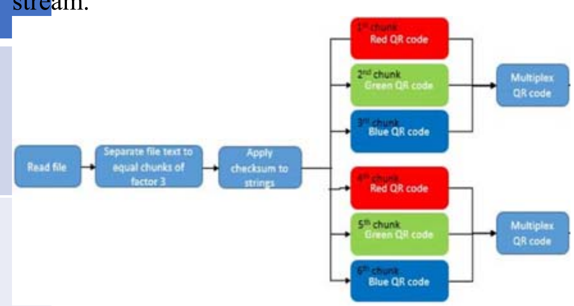


Figure 5: Sin Rong Toh, Weihan Goh and Chai Kiat Yeo, 2016 Endocer [8]

The receiver will capture the video stream. Then, compare the color QR codes inside each frame to remove duplicated frames. Next, each color in the QR code will be decoded by decomposing the color QR code in to its red, green, blue layer. This is followed by decoding those monochrome QR codes to get the original data.

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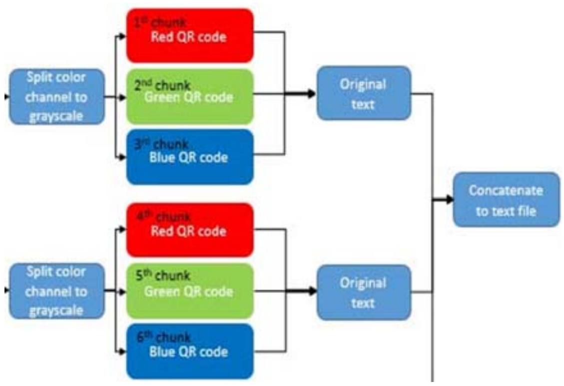

Figure 6: Figure 5: Sin Rong Toh, Weihan Goh and Chai Kiat Yeo, 2016 Decoder [8]

Our findings from this research work, is that it provides a new way for data exchange, but the decoder does not provide any color recovery algorithm resulting in low success rate which needs to be improved by 50%.

5.2 Research Work by Kikuchi, Fujiyoshi, Kiya, 2013

Authors have proposed color QR code to enhance the capacity of B/W QR code.

The sender will split the data in to 3 chunks. Each chunk is encoded into monochrome QR code (red, green and blue) then compose those three chunks into color QR code.

The receiver will decompose the color QR code into three monochromes QR code, then decode the monochrome QR codes and get the original file.

We found out that the system provides high capacity QR code, but the decoding success rate is 80% due to the color recovery for this algorithm which still needs to be improved**.**

5.3 Research work by Thilo Fath, Falk Schubert and Harald Haas, 2014

This research work is proposed for data transmission within an aircraft cabin. The data is transferred by stream of color QR code. In-Flight Entertainment (IFE) screen will be the sender, and the Passenger mobile will be the receiver.

The sender will split the file into equal chunks, then convert each chunk into color QR code, by splitting each chunk into 3 sub-chunks, then generate QR code for each chunk. The result will be red, green and blue QR code using color multiplexing to get colored QR code. Next, generate B/W QR code to store the frame number. Finally set those QR codes (B/W and Color) in a single frame and display on In-Flight Entertainment (IFE) screen.

The receiver will read the video stream from IFE screen, then decode color QR code by decomposing it into 3 monochrome QR codes which are red, green and blue then compose all the data according to B/W QR code in order to get the original file.
The sending and receiving process is shown in Figure 7.

From our findings, this system provides good solution for data exchange in airplane. However, the size for proposed color QR code can still be enhanced by using larger QR code version, and the decoding success rate 69% can also be improved by adding color recovery algorithm in the decoder.

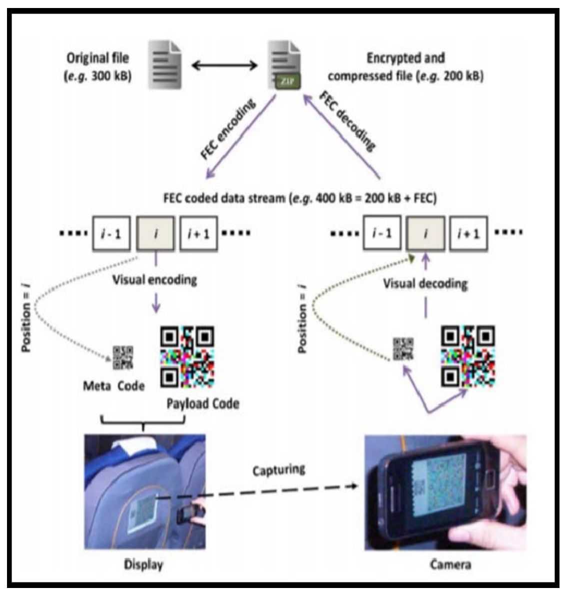

Figure 7: IFE screen Fath, Falk Schubert,and Harald Haas, 2014 System [5]

5.4 Comparison between Existing Systems

We compare the systems in four aspects which we use in our result comparison consisting of: (a) the maximum QR code version, (b) error correction level, (c) the camera capacity used in Megapixel (MP), and (d) success decoding rate as shown in Table 2. The success rate is the median of the success reading for the proposed QR code (Total success reading/ Total captured QR code).

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Table 3: Research Work by Thilo Fath, Falk Schubert and Harald Haas, 2014

Research Works	QR Code Version	Error Correction Level	Camera used in MP	Success Rate
(Sin Rong Toh, Weihan Goh, and Chai Kiat Yeo, 2016)	13	H	5	50%
(Thilo Fath, Falk Schubert,and Harald Haas, 2014)	14 13	M	8	69% 40%
(Kikuchi, Fujiyoshi, Kiya, 2013)	3	L	5	80%
Our Work	**3 13 14**	**L M, H L**	**5 8,5 8**	**93.3% 81.6% 80%**

From Table 3, it can be summarized that the maximum data capacity which can be hold per barcode = 3*23684= 71052 bit with success rate of 80% only. The result in Table 3 is used as a benchmark to compare the results with our work.

5.5 Proposed Decoder

For the sender, we are using the same color QR code generator algorithm used in our previous work [7, 5, 14]. We will split the file into 3 equal chunks. Then generate the QR code for each color: red, green and blue. Next, we compile the generated QR code to get color QR code. The generation process is shown in Figure 8.

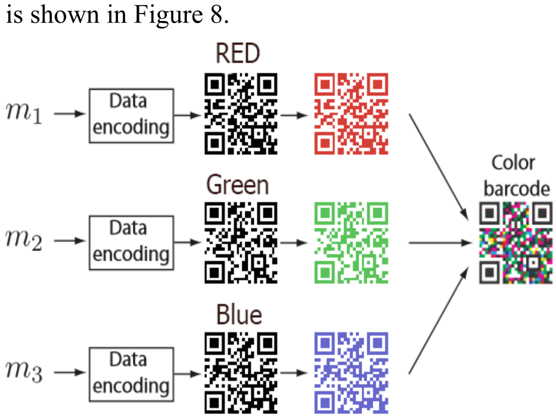

Figure 8: Data Encoding

The receiver is related to Figure 9 which shows the flow for data decoding. First, the color QR code is detected. Then, the image is converted to B/W for easy detection of the QR code. Next, we return the color to the QR code, followed by enhancing the color using fuzzy logic to obtain the color QR code. Finally, we split the color QR code into red, green and blue QR code and decoding it to get the original file.

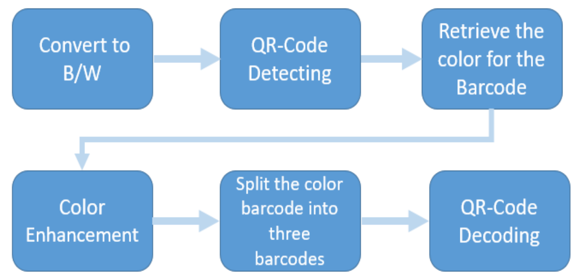

Figure 9: Decoding Process

6. Fuzzy Process

The proposed system has three inputs called R (red color feature), G (green color feature), and B (blue color feature) and an output enhanced color QR code. Figure 10 is an overview of the proposed fuzzy expert system. Triangular functions were selected from the encoded QR code the color value for (Red, Green, Blue) will be either 0 or 255. Therefore, for the receiver we need to return each color 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 value. Therefore, the triangle model with three heads was selected to determine the appropriate value for the color.

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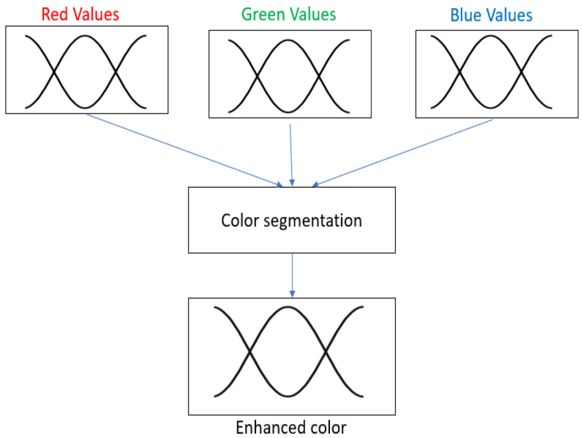

Figure 10: Fuzzy Process

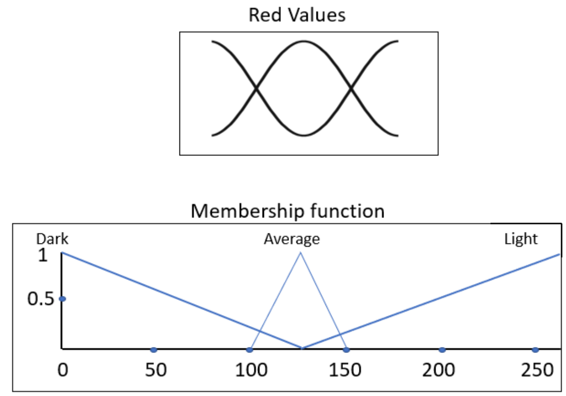

Figure 11: Red Value Membership Function

6.1 Fuzzification

In this system, the MAX operator is used for the fuzzification process. The MAX operator is used to select the color value (dark, average, light). For example, if the red color value was X we select R_{dark}, $R_{average}$, R_{light} using the membership functions that will be explained in section 6.1.1. and the maximum value will be the color value.

6.1.1 Red color input

The characteristics for red color input:
Red color component starts from 0 until 255, its lowest value belongs to darker red and the heights value lighter red.

This field can be divided into three membership functions. These functions share values with another input. Triangular functions were selected. Figure 11 shows the three membership functions for the R component.

The input membership function for the R component consists of:

- Minimum: 0.
- Maximum: 225.
- Average: 127.5.
- Color R (dark, average, light).

dark red= (0, 127)

$R_{dark}(x, 0, 0, 127)$

$$\begin{Bmatrix} 0 & x < 0 \\ \frac{127-x}{127} & 0 \le x \le 127 \\ 0 & 127 < x \end{Bmatrix}$$

average red= (127.5, 155)

$R_{average}$ (x, 100, 127.5, 155)

$$\begin{Bmatrix} 0 & x < 127.5 \\ \frac{127.5-x}{127.5} & 100 \le x \le 127.5 \\ \frac{150-x}{150} & 127.5 < x \le 150 \\ 0 & 150 < x \end{Bmatrix}$$

Light red= (127, 255)

R_{light} (x, 0, 127, 255)

$$\begin{Bmatrix} 0 & x < 127 \\ \frac{x}{255} & 127 \le x \le 255 \\ 0 & 255 < x \end{Bmatrix}$$

6.1.2 Green Color Input

The characteristics for green color input:
Green color component starts from 0 until 255, its lowest value belongs to darker green and the heights value lighter green.

This field can be divided into three membership functions. These functions share values with another input. Triangular functions were selected. Figure 12 shows the three membership functions for the G component.

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The input membership function for the G component consists of:

- Minimum: 0.
- Maximum: 225.
- Average: 127.5.
- Color G (dark, average, light).

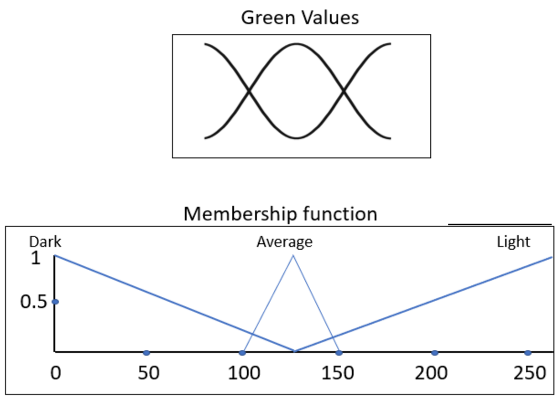

Figure 12: Green Value Membership Function

dark green= (0,127)
G_{dark}(x,0,0,127)

$$\begin{Bmatrix} 0 & x < 0 \\ \frac{127-x}{127} & 0 \le x \le 127 \\ 0 & 127 < x \end{Bmatrix}$$

average green= (127.5,155)
$G_{average}$ (x,100,127.5,155)

$$\begin{Bmatrix} 0 & x < 127.5 \\ \frac{127.5-x}{127.5} & 100 \le x \le 127.5 \\ \frac{150-x}{150} & 127.5 < x \le 150 \\ 0 & 150 < x \end{Bmatrix}$$

light green= (127,255)
G_{light} (x,0,127,255)

$$\begin{Bmatrix} 0 & x < 127 \\ \frac{x}{255} & 127 \le x \le 255 \\ 0 & 255 < x \end{Bmatrix}$$

6.1.3 Blue color input

The characteristics for blue color input:
Blue color component starts from 0 until 255, its lowest value belongs to darker blue and the heights value lighter blue.

This field can be divided into three membership functions. These functions share values with one another inputs. Triangular functions were selected. Figure 13 shows the three membership functions for the B component.

Input membership functions for the B component consists of:

- Minimum: 0.
- Maximum: 225.
- Average: 127.5.
- Color B (dark, average, light).

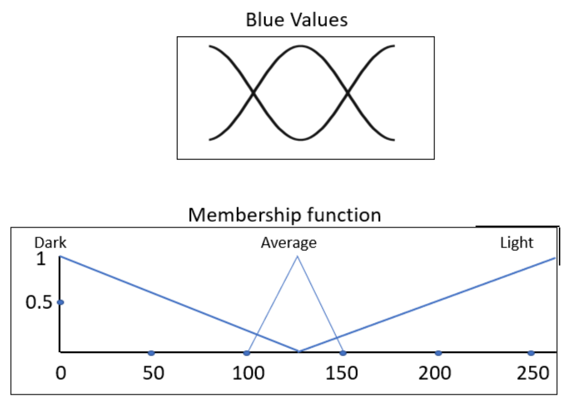

Figure 13: Blue Value Membership Function

dark blue= (0,127)
B_{dark}(x,0,0,127)

$$\begin{Bmatrix} 0 & x < 0 \\ \frac{127-x}{127} & 0 \le x \le 127 \\ 0 & 127 < x \end{Bmatrix}$$

average blue= (127.5,155)
$B_{average}$ (x,100,127.5,155)

$$\begin{Bmatrix} 0 & x < 127.5 \\ \frac{127.5-x}{127.5} & 100 \le x \le 127.5 \\ \frac{150-x}{150} & 127.5 < x \le 150 \\ 0 & 150 < x \end{Bmatrix}$$

light blue= (127,255)
B_{light} (x,0,127,255)

$$\begin{Bmatrix} 0 & x < 127 \\ \frac{x}{255} & 127 \le x \le 255 \\ 0 & 255 < x \end{Bmatrix}$$

6.2 Fuzzy Rules

Fuzzy rules are sets of variables conditions that lead to certain decisions. In this system the decisions made for the color component are red, green and blue. In defuzzification, we mix the fuzzy

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decision result for each color and get the enhanced color. In the proposed system, nine fuzzy rules are used and divided into three sets each, where each set refers to a specific color component and the fuzzy decisions for each color either min or max.

Red color rules:

1. If (R is light) then red color value is max
2. Else If (R is average) and (B is dark) and (G is dark) then green color value is max
3. Else red color is value is min

Green color rules:

1. If (G is light) then green color value is max
2. Else If (G is average) and (R is dark) and (B is dark) then green color value is max
3. Else green color is value is min

Blue color rules:

1. If (B is light) then blue color is value is max
2. Else If (B is average) and (R is dark) and (G is dark) then blue color value is max
3. Else blue color is value is min

6.3 Defuzzification

For this function, we get enhanced color value based on the fuzzy result. For the defuzzification process we get the result from the fuzzy rules for each color component. The generated color (red color result, green color result and blue color result) will have only eight possibilities as the sender QR code.

7. RESULTS AND DISCUSSION

We test our system with several QR code versions. First, five colored QR code version 13, a high error correction level, marked by H. This image is captured by iphone4 with 5 MP camera. Second, 306 colored QR code version 14 with medium error correction, marked by M. This QR code is captured by Samsung a9 with 8 MP camera. Third, 429 colored QR code version 17 with medium error correction, marked by M captured by Samsung a9 with 8 MP camera. Fourth, 20 colored QR code version 3 with low error correction, marked by L which is captured by iphone4 with 5 MP camera.

Table 4 shows the results for color QR code version 13 with high error correction. Figure 14 shows the comparison between our results and (Sin Rong Toh, Weihan Goh, and Chai Kiat Yeo, 2016) results.

Table 4 Results for Color QR Code Version 13 with High Error Correction

	QR-Code Version	Error Correction level	Camera used in MP	Success Rate
Our work	14	M	8 MP	81.6%
(Thilo Fath, Falk Schubert,and Harald Haas, 2014)	14	M	8 MP	69%

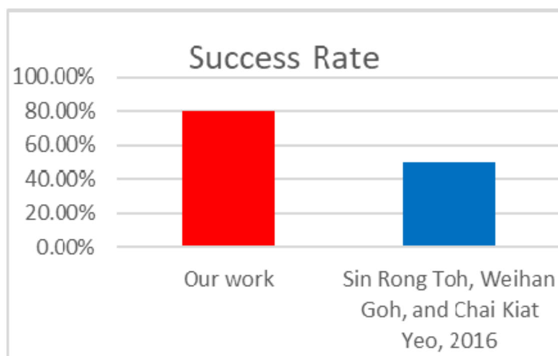

Figure 14: Comparison Between Our Result and (Sin Rong Toh, Weihan Goh, and Chai Kiat Yeo, 2016) Result

Table 5 shows the results for color QR code version 14 with medium error correction. Figure 15 shows the comparison between our result and (Thilo Fath, Falk Schubert,and Harald Haas, 2014) result.

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Table 5 Results for Color QR Code Version 7 with Medium Error Correction

	QR-Code Version	Error Correction level	Camera used in MP	Success Rate
Our work	13	H	5 MP	80%
Sin Rong Toh, Weihan Goh, and Chai Kiat Yeo, 2016	13	H	5 MP	50%

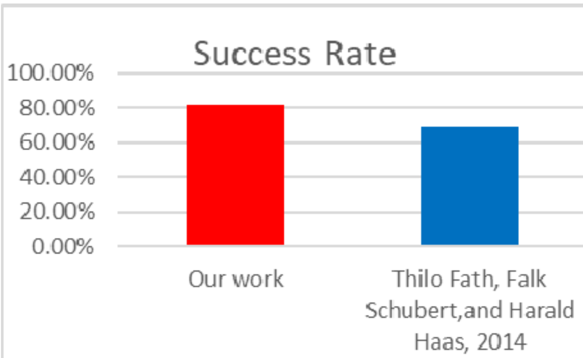

Figure 15: Comparison Between Our Result and (Thilo Fath, Falk Schubert,and Harald Haas, 2014) Result

Table 6 shows the results for color QR code version 17 with medium error correction. Figure 16 shows the comparison between our result and (Thilo Fath, Falk Schubert,and Harald Haas, 2014) result.

Table 6 Results for Color QR Code Version 8 with Medium Error Correction

	QR-Code Version	Error Correction level	Camera used in MP	Success Rate
Our work	17	M	8 MP	73.3%
(Thilo Fath, Falk Schubert,and Harald Haas, 2014)	17	M	8 MP	53%

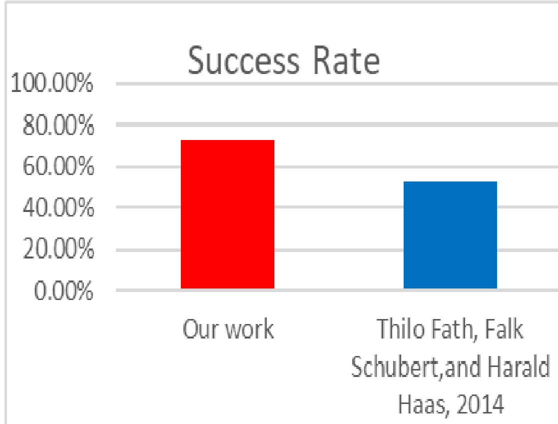

Figure 16: Comparison Between Our result and (Thilo Fath, Falk Schubert,and Harald Haas, 2014) result

Table 7 shows the results for color QR code version 3 with low error correction. Figure 17 shows the comparison between our results and (Kikuchi, Fujiyoshi, Kiya, 2013) results.

Table 7 Results for Color QR Code Version 3 with Low Error Correction

	QR-Code Version	Error Correction level	Camera used in MP	Success Rate
Our work	3	L	5 MP	93.33%
(Kikuchi, Fujiyoshi, Kiya, 2013)	3	L	5 MP	80%

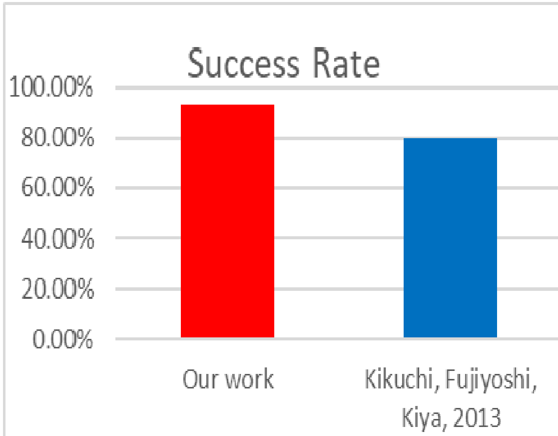

Figure 17: Comparison Between Our Result and (Kikuchi, Fujiyoshi, Kiya, 2013) Result

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8. ASSUMPTIONS

- The system is assumed to capture the QR code from computer screens, not from printed paper because the color format in screens is RGB, while in printers is CMYK.
- The distance between the mobile camera and the screen is 20 cm to 50 cm.
- The lighting when capturing the image is normal room lighting in-door.

9. CONCLUSION AND FUTURE WORKS

In this paper, we show the result comparison between or proposed color QR code decoder using fuzzy logic and other research work. The result proved that using fuzzy logic for the decoder produced better success rate.

For future works, the system will be tested for printed QR code on paper, the scanning speed and the distance between the screen and the mobile camera.

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