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MULTI-LAYER COLOR QR CODE DYNAMIC DECODER FRAMEWORK WITH FUZZY COLOR RECOVERY

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ABSTRACT

In this paper, we proposed a dynamic framework for a multi-layer color QR code decoder. The proposed decoder framework shows the general steps to decode color QR code. It contains a configuration setting standard that allows other researchers to refer in order to decode their color QR code based on the colors used in the encoder. The framework starts with color QR code detection, then search for color reference. This is followed by fuzzy sets selection based on the color QR code. Color enhancement for the QR code is implemented based on the fuzzy set decision. Next, is color de-multiplexing to get Black and White (B/W) QR code. The de-multiplexing process is based on a configuration file, for the QR code color setting. Finally, is the decoding and merging of the results for the B/W QR code to obtain the original file. We use two datasets with color reference to evaluate our framework. The first dataset used is generated by Yang et al., 2018 encoder and we obtained 83% success rate for the detection and color de-multiplexing. The second dataset is generated from our encoder and produced 90% decoding success rate. The experiment shows the framework can successfully work with different sizes of color QR code.

Keywords: *Fuzzy, Color QR Code, Decoder, Framework, Color Enhancement*

1. INTRODUCTION

QR code is a way to visualize the data to get a fast reading of the content using QR code scanners. QR codes have been used in many different fields, such as customer advertising, ticket system, website authentication, and business card [1], [2], [3], [4], [5]. Color QR code is an extended version of B/W QR code. The key feature for color QR code is the encoding data size which can reach up to 3 times larger compared to B/W QR code [2], [3], [4]. However, color QR code is still in its initial stage as it has two major issues, first, the low decoding success rate which is 45% [3] and second, the slow decoding speed which is 3 seconds [3]. Due to these limitations, we cannot identify much application for color QR codes and make it difficult to extend the data encoding size for the current color QR code. Current color QR code decoder is built for a specific type of QR code, based on the color used and the algorithm is used for color recovery, color reference, etc. As a result, adds difficulties to the end-user to find the correct decoder. Color recovery is a challenging part that causes low decoding success rate. In addition, fuzzy technique is powerful to recognize images such as bacteria [6] and skin color [7]. These facts motivate us to find a dynamic framework that can read different types of color QR code and have its own color enhancements algorithm based on fuzzy technique to decode current color QR code to produce better success rate and faster decoding time.

This research work is to propose a multi-layer dynamic color QR code decoder framework to allow color QR code decoder to decode different types of color QR code dataset, which allow us to evaluate applying fuzzy color recovery to enhance the speed and decoding success rate. The proposed decoder framework allows us to define the color used in the encoder dataset using a configuration file.

This paper consists of six sections. Section 2 explains about color QR code. Section 3 reviews the related research works. Section 4 is the proposed QR code decoder. Section 5 discusses the

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experiments and finally section 6 is the conclusion and future works.

2. COLOR QR CODE

Color QR code is an extension of B/W QR code by encoding multiple layers of B/W QR code and merging these layers to one color QR code [3], [4], [8], [9]. There are two types of color QR code with color reference [1], [3] and without color reference [2], [4]. For QR code with color reference, the finder pattern consists of colors which indicate the color in the QR code. Finder pattern will be explained in this section.

Color QR code has 40 different versions each version can encode a larger size of data, but in return will consume more space on paper. there are three factors which will affect the color QR code size as follows:

i. **Data type** which can be numeric, alphanumeric, binary and to send any type of data, it can be converted to data bits.

ii. **Error correction** consisting of four levels:

- Low (L) which can recover up to 7% damage data.
- Medium (M) which can recover up to 15% damage data.
- Quartile (Q) which can recover up to 25% damage data.
- High (H) which can recover up to 30% damage data.

The higher the error correction level, the less data can be encoded within the QR code.

iii. **Number of layers,** adding more layers in the color QR code helps to increase the data size. However, adding more layers requires a color recovery algorithm for the decoder, which is up to three color layers with an acceptable decoding success rate. Table 1 shows a color QR code specification.

TABLE 1. COLOR QR CODE SPECIFICATION

Symbol size	Min. 21x21 cell - Max. 177x177 cell (with 4-cells interval)		3 Color Layers
Maximum Data Size (version 40)	Data bits	10,208	30,624
	Numeric	3,057	9,171
	Alphanumeric	1,852	5,556
	Binary	1,273	3,819
Error correction	Level L	Up to 7%	
	Level M	Up to 15%	
	Level Q	Up to 25%	
	Level H	Up to 30%	

The color QR code structure consists of multi-layers of B/W QR codes, which can be divided into 9 functional patterns based on its functionality as follows:

i. **Finder pattern:** it is consisting of the three squares that surround the QR code. Its main function is to locate and detect the correct rotation for the QR code. In addition, some types of color QR code hold the encoding color information. The finder pattern is shown in Figure 1, marked as 1.

ii. **Separator pattern:** it is the space around the finder pattern. The main functionality is to isolate the finder pattern from other QR code pattern. the separator pattern is shown in Figure 1, marked as 2.

iii. **Timing pattern:** each QR code has two timing patterns one is horizontal, and the other is vertical. It consists of a black and white alternative model. The main functionality is to help the decoder on geometrical correction and to detect the start and the end for each model. Timing pattern is shown in Figure 1, marked as 3.

iv. **Alignment pattern:** it is the black square in the right bottom corner of the QR code. The alignment pattern starts from QR code version 2 and above. A higher version of the QR code has more alignment patterns. Its main functionality in the grammatical correction which explains why it is needed more in a larger QR code version. Alignment pattern is shown in Figure 1, marked as 4.

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v. **Format information:** it is located next to the separator pattern. It has information about the error correction rate and the data type. Format information is shown in Figure 1, marked as 5.

vi. **Data pattern:** it holds the actual data with the error correction code. The data is formatted as 0 for the black model and 1 for the white model. the data pattern is shown in Figure 1, marked as 6.

vii. **Quit zone:** it is the empty space around the QR code which is important to allow the decoder to locate the QR code. The quit zone is shown in Figure 1, marked as 7.

viii. **Reminder pattern:** it is the last two models in the first vertical column. It contained information about how many empty bits added to the QR code. So, the decoder removes them from the data. The reminder pattern is shown in Figure 1, marked as 8.

ix. **Color layers:** it is the layers of monochrome QR code that allow the color QR code to hold more data than the usual QR code. Using the color multiplexing, we can view those layers as single color in QR code. Color layers are shown in Figure 1 marked as 9, the black arrow.

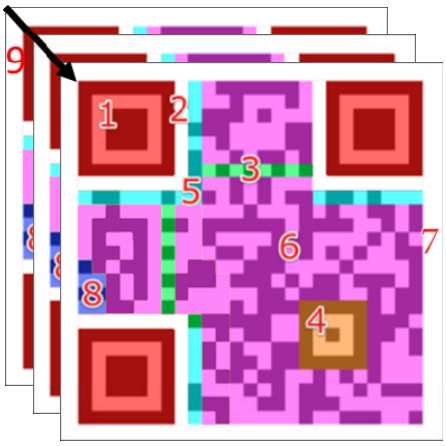

Figure 1: Color QR Code Structure

2.1 Color QR Code Encoder

Most of color QR code encoder follows the same steps as follows:

1- Split the file to equal chunks. The chunks should be equal so that the QR codes for each chunk will have same version.
2- Generate B/W QR code for each chunk. This is done usually using third party library such as ZXing.
3- Assign a color to each B/W QR code. The color should use primary color for easy color multiplexing process.
4- Merge all monochrome color QR codes into one colored QR code using color multiplexing.
5- If the color QR code generator supports color reference, then the final step is adding the color reference. Otherwise, step four is the final step.

The QR code generator process is shown in Figure 2 and the color multiplying step is shown in Figure 3.

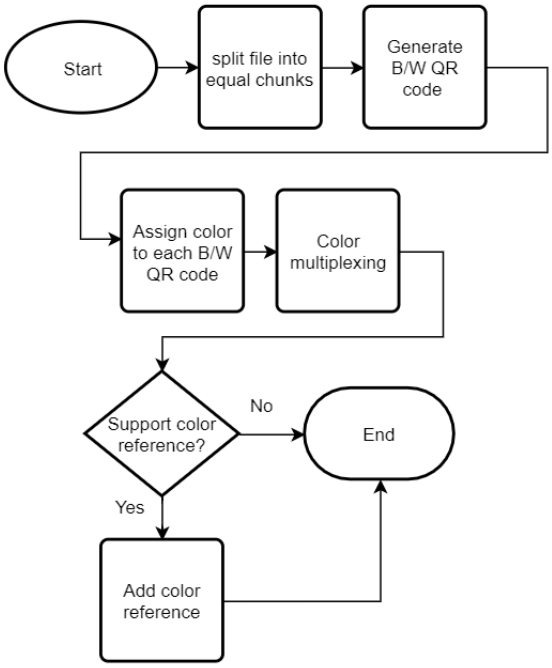

Figure 2: Color QR Code Encoder Process

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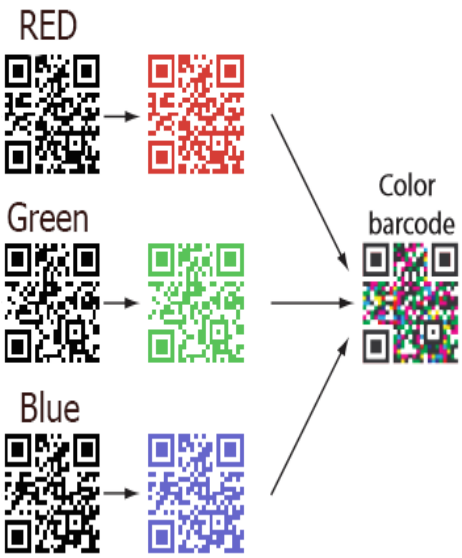

Figure 3: Color Multiplexing Process

2.2 Color QR Code Decoder

Most color QR code decoder follows the same steps in order to decode the colored QR code but, they vary based on image processing algorithm. The steps is as follows:

1- Detection and geomagnetic distortion correction which is mostly done using one of the open-source libraries such as ZXing library.
2- If the decoder support color reference then, gets color reference values otherwise, go to the next step.
3- Color enhancement where the image processing algorithm tries to get back to the original color.
4- Color de-multiplexing process to get the monochrome QR codes.
5- Decode monochrome QR codes and merge the result to get the original file.

The decoder process is shown in Figure 4.

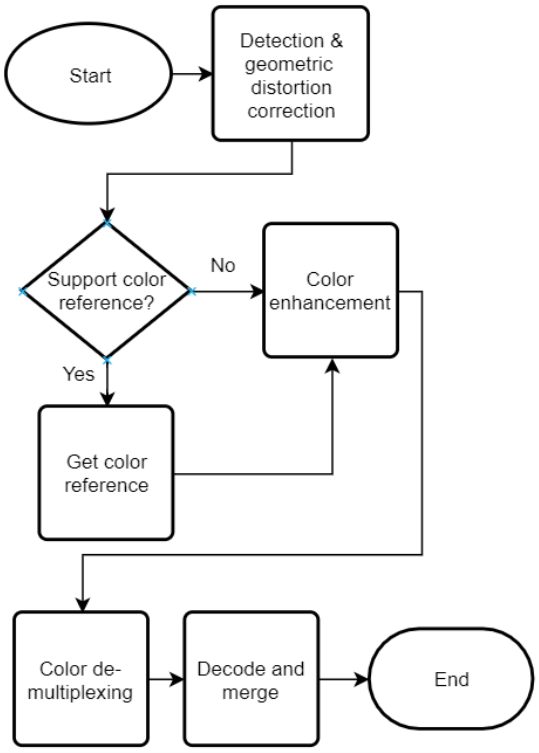

Figure 4: Color QR Code Decoder Process

3. RELATED RESEARCH WORK

This part explains in detail five research works which will be used as our benchmark. We will show the decoder part for each research work since our propose framework is for the decoder. Then we will show a comparison table between each existing system.

3.1 Research Work by Zhibo Yang, 2018 [3]

Their proposed color QR code is using color QR code with color reference.

The decoder uses quadratic discriminant analysis and support vector machine in the color enhancement process and proposed a color code book for color values. The decoding process is as follows:

1- Localization and geometric transformation to get the QR code in its correct rotation.
2- Learning based color recovery, which is done using support vector machine and discriminant analysis.
3- Color de-multiplexing using color code book.
4- Decode monochrome QR codes and merge the result to get the original file.

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Their proposed decoder is time-consuming although it is faster than other color QR code decoder, but it still needs around 3 seconds for color enhancement. This is due to the liner algorithm which means they need to scan the QR code for each color layer. Furthermore, their success rate is 46%, because machine learning algorithm is utilized, and offline learning is used for color recovery. Their decoder step is shown in Figure 5.

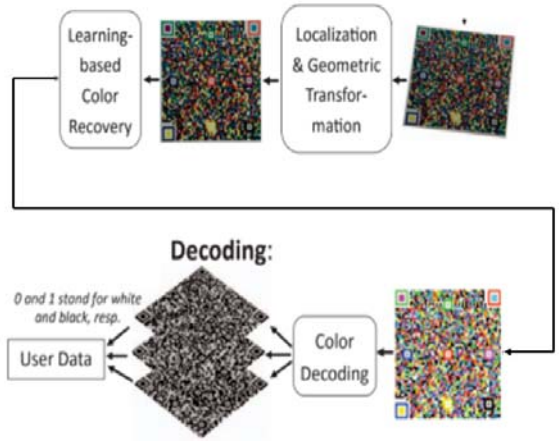

Figure 5: Decoder Steps (Yang., 2018)[3]

3.2 Research Work by Blasinski, Henryk, 2013 [4]

Their proposed color QR code is using color QR code without color reference.

The decoder model the color QR code using Kubelka-Munk theory to get the color value in the color enhancement process. The decoding process as follow:

1- Localization and geometric transformation to get the QR code in its correct rotation.
2- Color recovery using Kubelka-Munk theory.
3- Repeat step 3 for all color (cyan, magenta, yellow).
4- Color de-multiplexing using CMY color format.
5- Decode monochrome QR codes and merge the result to get the original file.

The proposed decoder is time-consuming because they are using liner algorithm which means they need to scan the QR code for each color layer. Furthermore, their success rate is 25.73%, which is due to their proposed color recovery algorithm. Decision making function is unavailable to solve the color illumination issue. Their color modelling is shown in Figure 6.

Figure 6: Decoder Steps (Blasinski., 2013)[4]

3.3 Research Work by Nivedan Bhardwaj, 2016 [9]

Their proposed color QR code is using color QR code with color reference.

The decoder uses image processing techniques (luminance increase, color thresholding, binarisation, etc.) in the color enhancement process. The decoding process is as follows:

1- Detection for color QR code.
2- Color recovery using image processing techniques. To enhance the color.
3- Color de-multiplexing using RGB color format.
4- Decode monochrome QR codes and merge the result to get the original file.

The proposed decoder is time-consuming because they are using many image processing steps. Their success rate is 20% which is due to their proposed color recovery algorithm. In addition, decision making function is not provided to solve the color illumination issue. The overview of their decoder is shown in Figure 7.

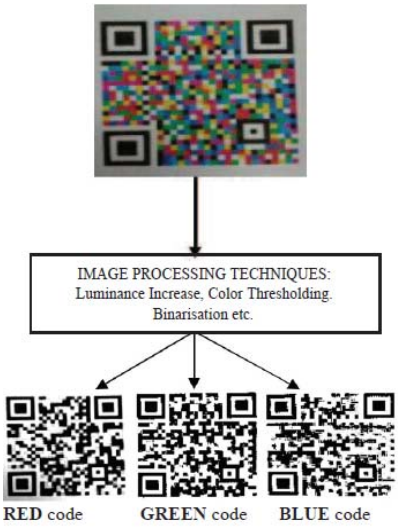

Figure 7: Decoder Steps (Bhardwaj., 2016)[9]

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3.4 Research Work by Sin Rong, 2016 [5]

Their proposed color QR code is using color QR code without color reference.

The decoder uses color threshold in the color enhancement process. The decoding process is as follows:

1- Detection for color QR code.
2- Color recovery using color threshold. To enhance the color.
3- Color de-multiplexing using RGB color format.
4- Repeat steps 1,2,3 for all color QR codes frames
5- Decode monochrome QR codes and merge the result to get the original file.

The proposed decoder does not perform any color recovery algorithm which makes this decoder limited only for small QR code versions with 40% success rate. In addition, the decision-making function is not provided to solve the color illumination issue. The overview of their decoder is shown in Figure 8.

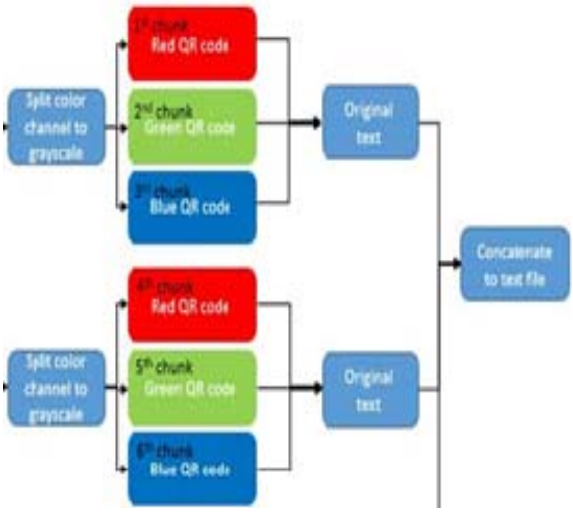

Figure 8: Decoder Steps (Rong, 2016)[5]

3.5 Research Work by Fath Thilo, 2014 [11]

Their proposed color QR code is using two QR codes one is colored which holds the data and the other is B/W which has metadata. The decoding process as follow:

1- Detection for black and white QR code.
2- Detection for color QR code.
3- Decode black and white QR code to get metadata about color QR code.
4- Color enhancement for color QR code.
5- Color de-multiplexing using RGB color format.
6- Repeat steps 1 to 5 for all color QR codes frames.
7- Decode monochrome QR codes and merge the result to get the original file.

The decoder needs to decode both QR codes to get the data. The proposed decoder is time-consuming due to the need to decode additional B/W QR code, furthermore like the color recovery algorithm which makes this decoder limited only for only small QR code versions. In addition, decision making function is not provided to solve the color illumination issue. The overview of their decoder is shown in Figure 9.

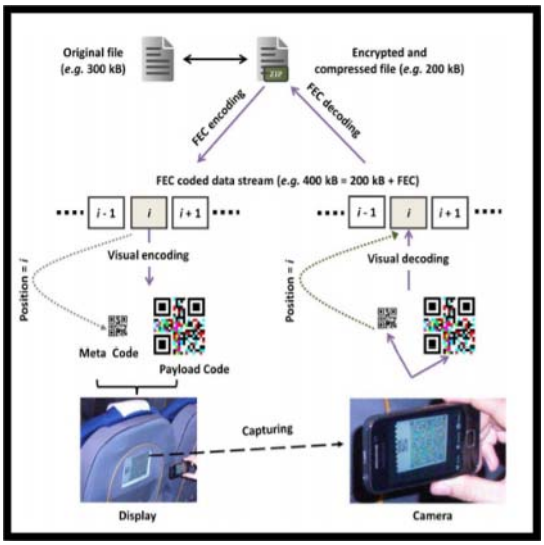

Figure 9: Decoder Steps (Fath., 2014)[11]

3.6 Comparison between Existing Systems

We compare the systems in six aspects consisting of: (a) the camera (b) support color reference (c) number of colors (d) success rate (e) decoding speed and (f) algorithm used, as shown in Table 2. From Table 2, the best success rate produced is 46% with a decoding speed of 3 seconds.

4. PROPOSED FRAMEWORK

We proposed a framework that can read color QR code and enable a configuration file for this framework to allow the decoder to decode custom color code. The proposed framework utilized fuzzy technique for color enhancement as follows:

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1- Detect the color QR code, then make localization and geometric distortion correction to get QR code with its original rotation.
2- Search for reference color if exist.
3- If the reference color does not exist, we define a predefined reference color.
4- Build fuzzy sets based on the color reference.
5- Return all the colors in the detected QR code to its original color based on the fuzzy sets from step 4.
6- Check the configuration file in the color code book.
7- Split the color QR code to monochrome QR code.
8- Decode the monochrome QR codes.
9- Merge the decoding result to get the original data

The proposed decoder is shown in Figure 10.

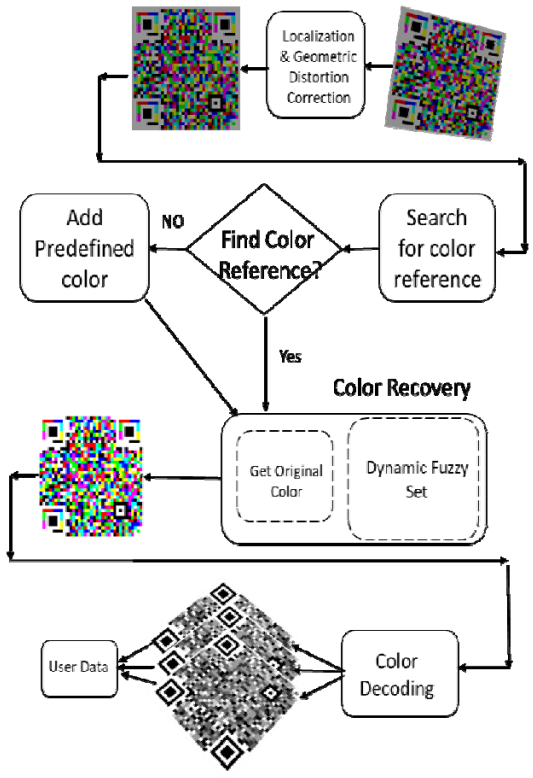

Figure 10: Proposed Framework

4.1 Color Recovery

We extend the color recovery in two steps: (a) build dynamic fuzzy set (b) color enhancement based on fuzzy results.

4.1.1 Build Dynamic Fuzzy Set

For color QR code which supports color reference, we will use the values for color reference to build the fuzzy set and for QR code without color reference we add predefined color values as color reference to build the fuzzy sets. The fuzzy set is built as follows: take all reference values for specific color, then we take the smallest reference value and largest reference as, color range. Then, we use this color ranges as fuzzy sets. Figure 11 shows an example of color reference for red color.

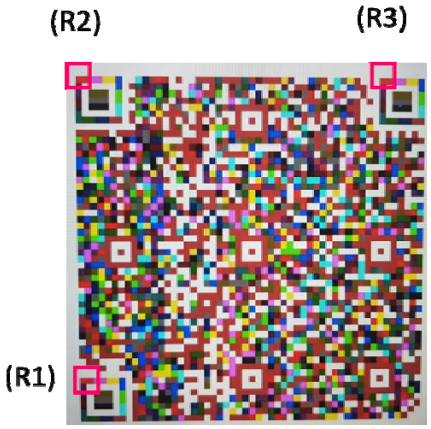

Figure 11: Color Reference for Red Color

4.1.2 Color Enhancement

We loop over all models in color QR code and check the fuzzy rules to decide the actual color for the selected model. Fuzzy decision works as follows:

i. **Fuzzification:** convert the color into its numeric value (R, G, B)

ii. **Membership Function:** the membership will check if the color belongs to any color range.

Figure 12 shows the membership functions which consists of:

- Each color ranges
- Color output (Red, Green, Blue and Yellow).

The color range consists of the minimum and maximum value from the color reference. From the example in Figure 11, the minimum for red color is the min value of (R1, R2 and R3) and the maximum for red color is the max value of (R1, R2 and R3).

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The output of the membership function will be the color name. The min and max values and the output color is based on the reference color.

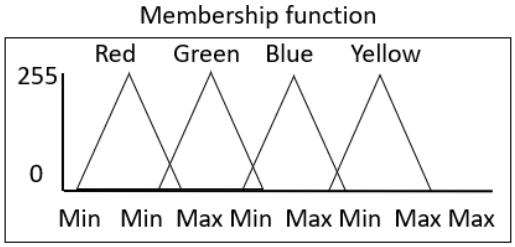

Figure 12: Membership Function

The fuzzy rules will decide the color value for the selected color model based on the color reference and membership output. The rule is as follows:

if the selected color belongs to only one, color range
then the color is in same color range
else if the selected color does not belong to any color range **and**
if the color value is more than 127, **then** the color is white
else if the selected color does not belong to any color range **and**
if the color value is less than 127, **then** the color is black
else the color value is the nearest color value among color reference

In the **de-fuzzification** process, the color value is converted to the actual color.

4.2 Obtaining Color Code from Config File

The main purpose of the config file is to allow different color encoding, for example, red as the default encoding will be 1,0,0. But for some color QR code, the encoding is 0,1,0. So the config file basically has all color and its encoding. The config file helps in color de-multiplexing process to get the original B/W QR code.

5. RESULT AND DISCUSSION

For evaluation, we test our system using two datasets first dataset is from (Yang et al., 2018) research, consisting of 1,506 photos and 3,884 camera previews of high-density 3-layer color QR codes captured by different phone models under different lighting conditions. We evaluate our decoder in terms of color recovery speed. The comparison result is shown in Figure 13. Table 3 compares the result of our proposed framework and (Yang et al., 2018) in terms of color recovery speed. The result shows that our proposed framework can decode the QR code, worst case of 1.2 seconds.

TABLE 3. COLOR RECOVERY SPEED COMPARISON BETWEEN OUR PROPOSED FRAMEWORK AND (YANG ET AL., 2018)

QR Code Size	Yang, 2018[3]	Our Framework
8900 bytes	5 seconds	1.2 seconds
8200 bytes	4 seconds	1.1 seconds
7600 bytes	3.5 seconds	1.1 seconds
7000 bytes	3 seconds	1 seconds

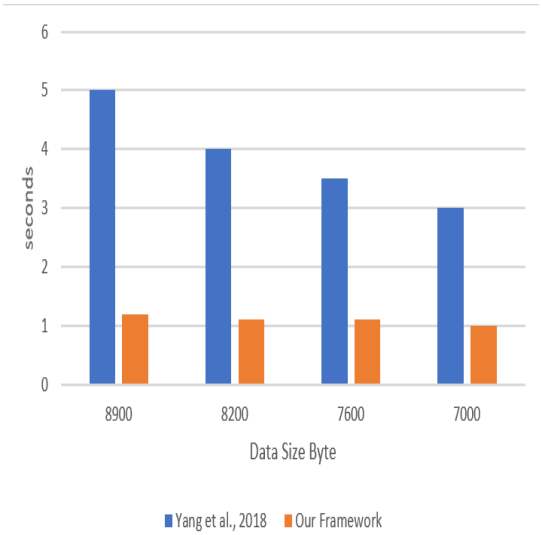

Figure 13: Color Recovery Speed Comparison between Our Proposed Framework and (Yang et al., 2018)

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For the second dataset, we generate QR codes using our own generator (Badawi et al., 2019). The dataset consists of ten color QR code for version 10, ten for version 15 and ten for version 19, with a total of 30 color QR codes. The result shows that our proposed decoder can decode color QR code with a success rate of 90% and color recovery speed of 1 second. Table 4 shows the second dataset results.

TABLE 4. SECOND DATASET RESULTS

QR Code Version	Success Rate	Color Recovery Speed
10	90%	1 second
15	80%	1.2 seconds
19	80%	1 second

We also compared the result we obtained from the second datasets with other existing work, in terms of decoding speed and decoding success rate, shown in Table 5. The results show by using fuzzy technique, produced up to 90% success rate compared to 46% [3] which is the best success rate for existing work. In addition, produced 1 second decoding speed compared to 3 [3] seconds for the fastest decoding speed in the existing work.

TABLE 5. SECOND DATASET RESULTS

Research Works	Success Rate	Decoding Speed
(Yang, 2018) [3]	46%	3 seconds
(Blasinski, 2013)[4]	25.73%	-
(Bhardwaj, 2016)[9]	20%	-
(Rong, 2016)[5]	-	50 seconds
(Fath, 2014)[11]	Can decode up to version 9	-
Our proposed decoder	90%	1 Second

The recovery speed is calculated as follows:

$$\text{Percentage Difference} = \frac{|V_1 - V_2|}{|V_1|} \times 100$$

where V1 is our proposed framework decoding speed and V2 is the best decoding speed from other research work [3].

Based on the Percentage Difference formula and Table 5 under column Decoding Speed, we obtained a 200% recovery speed as follows:

$$\text{Percentage Difference} = \frac{|1 - 3|}{|1|} \times 100 = 200\%$$

6. CONCLUSION AND FUTURE WORKS

In this paper, we explained about our proposed color decoder framework for both type of color QR code with/without color reference. A configuration file for the decoder allows us to have general steps for most color QR code decoder. We include fuzzy technique in color recovery to get better success rate. We proved that using fuzzy technique for color enhancement process can improve the color recovery speed as well as the success rate.

For future works, we will test our framework with more datasets in terms of the success rate and color recovery speed, as well as compare with other research works.

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Table 2. Comparison with Existing Works

Research Works	Camera Megapixel	Support Color Reference	Number of Color	Success Rate	Decode Speed	Algorithm Used
(Yang, 2018)[3]	8M	Yes	8	46%	3 seconds	Quadratic Discriminant Analysis and Support Vector Machine
(Blasinski, 2013)[4]	5M	No	8	25.73%	-	Diffuse reflection
(Bhardwaj, 2016)[9]	5M	Yes	8	20%	-	Color multiplexing
(Rong, 2016) [5]	5M	NO	8	-	50 seconds	Color de-multiplexing
(Fath, 2014)[11]	5,8	NO	8	Can decode up to version9	-	Meta data QR