Dual Image QR Codes: The Best of Both Worlds

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***Abstract*—Due to the high adoption rate of QR codes across the world, researchers have been attempting to improve classical QR codes by either improving their appearance to be more meaningful to human perception or improving their capability to store more messages. In this work, we propose dual image QR codes that aim to improve both aspects while preserving the ability to scan by standard QR code readers. We improve the appearance of the QR code using the halftone QR principle and increase the capacity of the QR code with the lenticular imaging technique. To test the robustness of the proposed QR code, we evaluated six important parameters and searched for appropriate conditions through $24,000$ combinations. From the experiments, we found $3,714$ appropriate conditions which achieved 100% successful scanning rate. Lastly, we also list examples of use cases to use in real-world situations for the proposed dual image QR codes.**

***Index Terms*—QR code, Aesthetic, Increase Capacity, Lenticular**

I. Introduction

The Quick Response (QR) code was introduced in 1994 by Masahiro Hara [1] to solve the limited capacity of the barcode, up to 20 characters. The QR code could store $7,089$ characters, including Kanji, Kana, and alphanumeric; and it could be scanned from any angle out of $360°$. In addition, the QR code has short response time and robust to noise in the code. Recently, QR codes had been widely used throughout the globe. The adoption is as high as 34% of the world population in 2017 [2]. In addition, the pandemic, Covid-19, stimulated QR code mass adoption as the primary payment method, 56% of people agreed to use the QR code as their main payment method in 2021. The QR code reader has been a built-in function in the native iPhone camera since iOS version 11 [3].

However, researchers have still been trying to improve the QR code for both the aesthetic [4]–[9] and the capacity [10]–[13]. In this work, we are interested in improving both aspects simultaneously by introducing the dual image QR codes which the outlooks are understandable by a human while containing two messages. The dual image QR codes, which user can observe two meaningful appearance QR codes from two different angles and scan to retrieve two different messages from each of the QR codes with standard QR code readers, is shown in Figure 1.

Contributions of this work are two folds. First, we modify the halftone QR codes to make the QR codes more aesthetic and understandable to a human. Second, we use the lenticular imaging concept to double the message capacity of the QR codes. We evaluate the robustness of our proposed Dual Image QR code through vigorous tests and outline appropriate settings for the dual image QR code to use in a real-world situation.

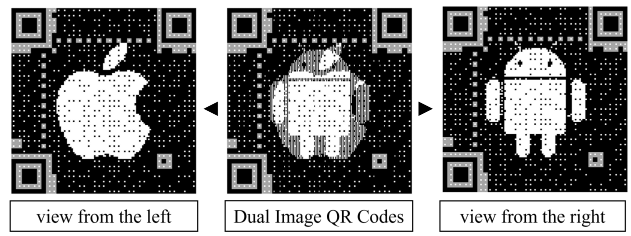

Fig. 1. Dual Image QR Codes encrypt two messages in two images.

Examples of use cases of the dual image QR codes are as follows. First, the owner of the mobile application could advertise the app through a dual image QR codes card. When the customers observe from the left, they see the Android logo. Scanning the logo will direct them to the Google Play Store. When the customers observe from the right, they see the Apple logo. Scanning the logo will direct them to the Apple App Store (pair-10 in Figure 9). Second, the restaurant could use the dual image QR codes as a food/dessert ordering portal. When observing from the left angle, the code illustrates the image of the cake. Scanning it will direct the customers to the dessert ordering web page. On the other hand, when observing from the right angle, the code illustrates the image of spoon and fork. Scanning it will directs the customers to the food ordering web page (pair-6 in Figure 9).

II. Related Work

In this section, we categorize research into attempts to beautify the meaningless pattern of the original QR code and attempts to increase the capacity of the original QR code.

A. Aesthetic QR Code

Due to the original QR code being an image of black and white squares placed in a meaningless pattern to human perception, researchers proposed modifications to beautify the QR code which makes it able to hint what information is behind the cluttered pattern. Russ Cox [4] proposed QArt codes that encoded input image as numeric data and placed it at the end of the input message as binary garbage. Chu *et al.* [5] proposed halftone QR codes that modify modules based on the nature of

QR code scanners which read a module as either '0' or '1' from the central pixels of the module. This allows them to replace a square module with arbitrary patterns as long as the pattern keeps the central pixels as is. Garateguy *et al.* [6] utilized the same trick as the halftone QR codes but allow the code to embed color images in the proposed QR codes. Hung *et al.* [7] also proposed micrography QR codes that replace the square module with micrography. The main contribution of the method is a process to modify micrography to maintain the central pixels of the original QR code module. All of the work, as mentioned above, only modify the QR code itself but does not change the decoding part. So all of the QR codes can be scanned by standard readers. However, there are work that modify both the encoding part and the decoding part such as the infrared watermark [8] and PiCode [9]. Although this line of work outputs more attractive codes, users must use a special scanning tool. We agree with the former, which only modifies the encoding part so that the output QR code can be scanned with the standard scanners.

B. Increasing Capacity of the QR code

Galiyawala *et al.* [10] proposed increasing the capacity of QR codes using colors based on three color channels so that one QR code can contain three messages. However, the encoded QR code in this work needs a specialized tool to decode, the code cannot be scanned by standard QR code readers. Tkachenko *et al.* [11] proposed a two-level QR code that modified QR modules to encode the message on the second level. In this work, the message in the first level can be scanned with standard QR readers, while the message in the second level requires a customized tool to decode the message. Furthermore, Arora *et al.* [12] increased the capacity of the QR code by using five high-contrast shades to encode five different messages. This work also requires their own decoding tool. In contrast, Yuan *et al.* [13] proposed two-layer QR codes which used an acrylic sheet to add more layers to the original QR code and can be scanned by standard QR code scanners. The additional layer was used to add modification modules '0', '1', and transparent, which modify the base modules in the base layer so that the QR codes encode different messages if they were looked from different angles. However, the cluttered pattern of the QR code hinders the real application of this method because users could not notice a perfect angle from the appearance of the two-layer QR code. This inspired us to add appearance hints to the QR code and use a lenticular lens instead of the acrylic sheet due to the cost and the creation process.

C. Lenticular Imaging

Lenticular imaging was introduced in 1930 in the film industry [14]. It was then adopted and used in several applications. Žiljak *et al.* [15] created flip-flop images with the lenticular technique. Weissman [13] used a lenticular lens to create the 3D effect by interlacing up to 20 images from slightly different angles. We use the lenticular lens to embed two different images which can be seen from different angles similar to the flip-flop image.

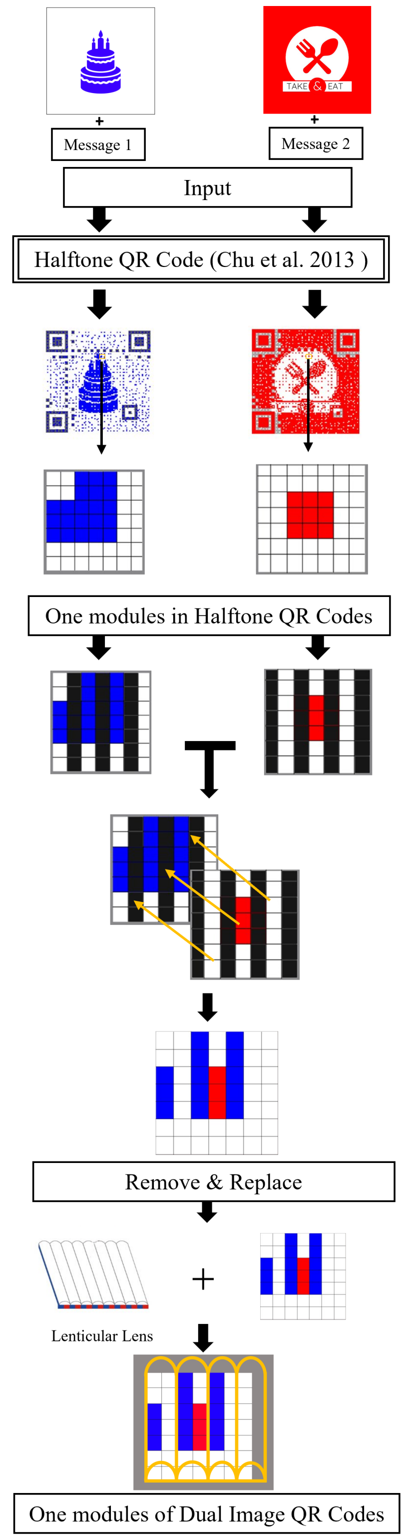

Fig. 2. Dual Image QR Codes generation procedure. The blue color represents the image on the left which can be seen from the right angle through the lenticular lens; and vice versa for the red color. Squares represent image pixels.

III. Dual Image QR Code

A. Dual Image QR Code Generation

The dual image QR codes aims to rearrange cluttered patterns so that they can have meaningful appearances for the human observer and increase the number of encrypted messages. For appearance, we adopt the pattern modification method of Chu *et al.* [5]. For capacity, we use the idea of the lenticular image to fuse two images into one. An overview of the process to generate the dual image QR code is shown in Figure 2.

The generation steps are as follows,

1) The inputs of the Dual Image QR Codes are two pairs of messages and their corresponding images.
2) The process starts by generating a halftone QR code for each message-image pair [5]. Each image column is set to one pixel wide so that one column of the lenticular lens covers two pixels of the image. One module of the QR code is set to 7×7 pixel^2 (sub-modules).
3) Half of the contents of both halftone QR codes from the previous step are removed and replaced with content from the other halftone QR code. Image columns from 2 different halftone QR codes are interlaced after removing half of the content from both halftone QR codes
4) The lenticular lens is placed on top of the merged halftone QR codes (fusion image), creating the dual image QR codes.

The pseudo-code for generating the fusion image is described in Algorithm 1, where msg1 and msg2 are the messages that we are encrypting, im1 and im2 are corresponding images that provide visual cues for the messages, and LPI is the lenticular lens spec which describes the number of lenses per inch.

Algorithm 1 Pseudo-code for generating the merged halftone QR codes (fusion image).

Input: msg1, msg2, im1, im2, LPI
Output: fusion_im

```
hfqr1 ← halftone_qr_generator(im1,msg1)
hfqr2 ← halftone_qr_generator(im2,msg2)
hfqr_r ← set_res(hfqr1,lpi)     ▷ set img resolution with (1)
hfqr_l ← set_res(hfqr2,lpi)     ▷ set img resolution with (1)
w ← get_width(hfqr_r)
for i ← 0 to w/2 − 1 do         ▷ interleave 2 images
    fusion_im[i] ← hfqr_r[2 × i]
    fusion_im[i+1] ← hfqr_l[(2 × i) + 1]
end for
```

B. Modules Fusion under Lenticular

An underline principle behind the dual image QR codes is based on the decoding procedure of standard QR code readers. After the code localization process, the QR code reader binarizes the QR image and interprets each bit (module) as '0' or '1' from the central pixel of the module. The halftone QR codes algorithm applies the principle by dividing the module into smaller sub-modules which the central sub-module preserves the value of the module and the other sub-modules are allowed to have different values. The algorithm then finds an optimal regenerated module which looks alike part of the image while preserving the value of the module at the central sub-pixel. Dual Image QR codes work further on this by dividing a module into seven columns and interlacing columns from different modules next to one another. When observers view the module through the lenticular from the left angle, the observers will see the magnified version of the right columns, and vice versa for viewing from the right angle. Figure 4 shows the examples of left and right modules when fusion with each other and when they are observed through the lenticular from different angles.

IV. Performance of Dual Image QR Code

A. Experiments

This section explains our experiments, designed to evaluate the robustness of the proposed dual image QR codes. The primary purpose of the experiments is to measure the success rate of the decoding through various conditions, which can be grouped as QR code generation settings and scanning conditions.

For QR code generation settings, we varied error correction levels (e), QR code version (v), and input image pairs (i), all dual image QR codes used in the experiments are shown in Figure 9. Error correction levels (e) is the parameter that indicates how much signal noise allowed for the QR scanner to be able to decode the message. We investigated all four levels of the error corrections (EC): ECL, which allows 7% noise; ECM, which allows 15% noise; ECQ, which allows 25% noise; and ECH, which allows 30% noise. QR code version (v) is the parameter that indicates the capacity of the QR code. The higher version, the larger capacity and the finer detail. In the experiments, we investigated five versions, version1-5. Moreover, a variety of input image pairs (i) were used to explore appropriate input images. We investigated 10 pairs of images combinations of 1-bit, 8-bit, and 24-bit images. The images had either black or white backgrounds.

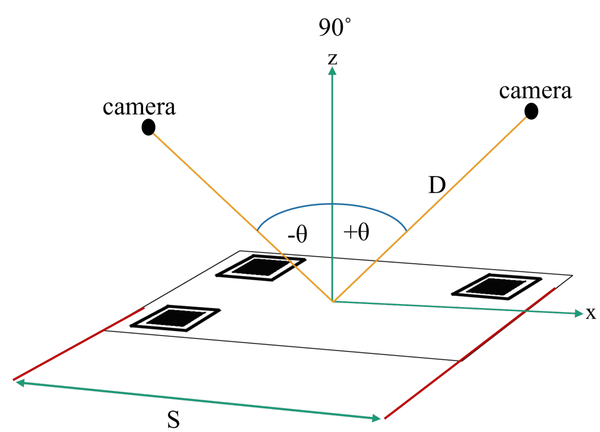

Fig. 3. Scanning condition settings.

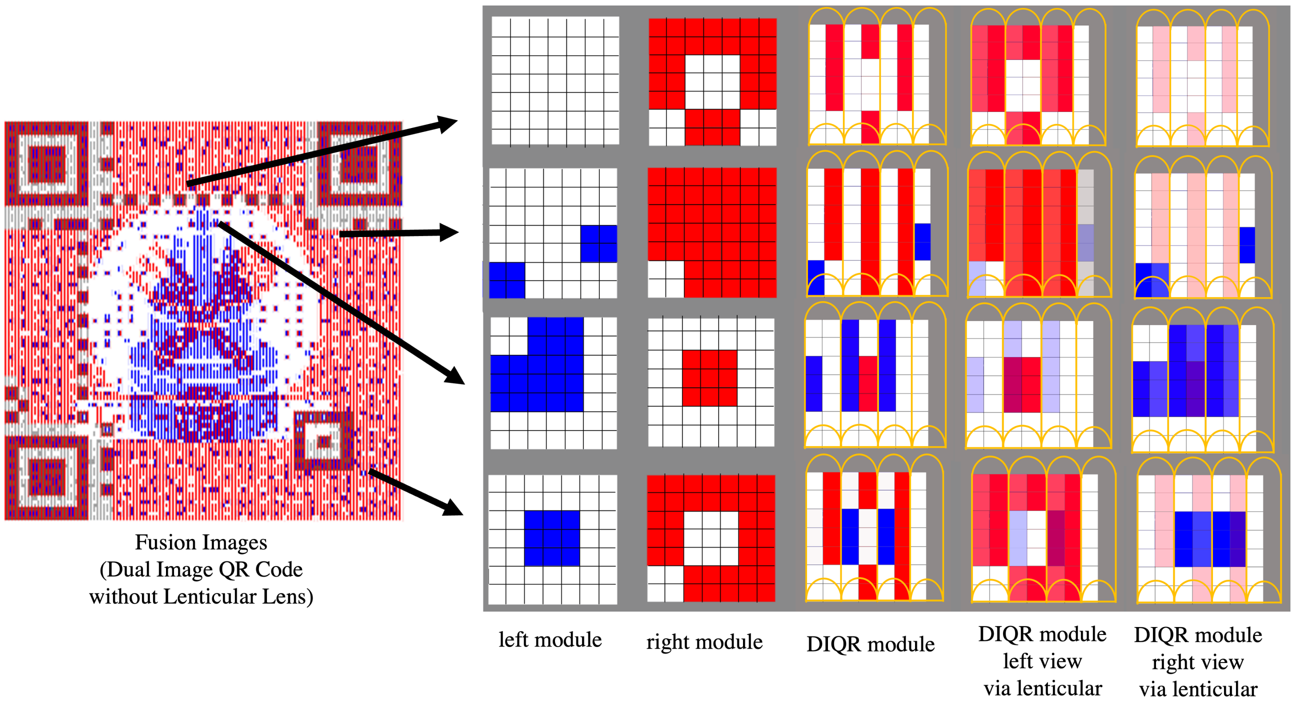

Fig. 4. Dual Image QR (DIQR) codes when zoomed-in to look at modules and how two modules fusion. DIQR module left view simulated how the module looks like when seen through the lenticular from the left, and vice versa for the DIQR module right view.

For scanning conditions, we varied distances between the scanner and the QR code (D), scanning angles (θ), and sizes of the QR code (S), detail of the scanning conditions can be found in Figure 3. In the experiments, we investigated 5 distances (D): 10cm, 15cm, 20cm, 25cm, and 30cm. For the scanning angles (θ), we investigated eight angles: four to the left and four to the right ($-50°$, $-40°$, $-30°$, $-20°$, $20°$, $30°$, $40°$, and $50°$). Lastly, the sizes of the QR codes (S) were 3inches (3×3), 4inches (4×4), and 5inches (5×5).

In the experiments, we scanned all different combinations of the conditions with an iOS built-in QR scanner. We used iPhone13Pro Max with iOS version 15.5 in this study. We scanned each condition for 10 times and each time we allowed up to 10 seconds to deem a successful scanning. The lenticular lens used in the experiment was a lenticular lens with 50 lenses per inch (LPI). The resolution of input images after passing through halftone QR was set to 100 pixels per inch (PPI). To apply the method with different sizes of the lenticular lens, the PPI of the input images for the Remove & Replace step should be set using (1)

$$PPI = 2 \times LPI \tag{1}$$

B. Result

After collecting the scanning results for $24,000$ conditions ($e \times v \times i \times D \times \theta \times S$), each condition 10 times, the success rate of each variable is shown in Figure 6. For error correction, we found that the higher error correction level gave a higher successful scanning rate. The highest successful scanning rate error correction was ECH. For the QR code version, version2, version3, and version4 achieved the highest success rate. Furthermore, the experiment showed that for the finer detail, after the QR code version4, our technique introduced more noise into the signal, which affected the successful scanning rate. For input image pairs, pair6, which is a combination of 8-bit with a black background and 1-bit with white background, gave the highest success rate. In addition, 1-bit pairs, pair-1 and pair-3, also showed promising results. It is worth to note here that the input image 8-bit-b1 had 0% success rate that made pair-2, pair-5, and pair-7 under-performed.

For the scanning condition, the distances (D) did not significantly affect the success rate, but 25cm is the most appropriate distance in the experiment. The best angles (θ) for both left and right views are $40°$. Finally, the size (S) 3inches QR code performed the best under our limited distance and angle. The larger distance and angle would have given a higher success rate for the larger size.

Moreover, we collected all six combinations that had 100% success rate and found that $3,714$ combinations out of $24,000$ combinations achieved 100% successful scanning rate. The best combination was error correction level high, QR code version4, image pairs between the 1-bit white background and the 8-bit black background, and scanned at 30cm distance, $40°$ left or right, and the size of QR code was 3inches. The distributions of 100% successful parameters are illustrated in Figure 8.

V. Visual Perception

We further investigated the visual cue of the dual image QR codes with the 13 participants in four simulated scenarios, as illustrated in Figure 5. In each scenario, participants were briefed about the scenario, showed the dual image QR codes, asked to describe image in each view, and asked to guess what is the encrypted message inside the QR code. The dual image QR codes used in the experiment were set to 3×3 inches^2, error correction high (ECH), and QR code version 4. For the simulated scenarios, the dual image QR codes were used as follows,

1) as a menu in the restaurant
2) as an entertainment platform promotional flyer
3) as a mobile app advertisement card
4) as an information signpost in a fashion shop

From our experiment, the participants could easily describe images in scenarios-1, 3, and 4 correctly; but the music note image in scenario-2 had low visual quality. 30.77% of participant found the music note is hardly visible. For the visual hinting, most of the participants guessed the encrypted messages in the same directions, as shown in Figure 7, e.g. scanning the image of a fork and spoon returns the food menu and scanning the image of a man icon returns the shopping portal for men's clothes.

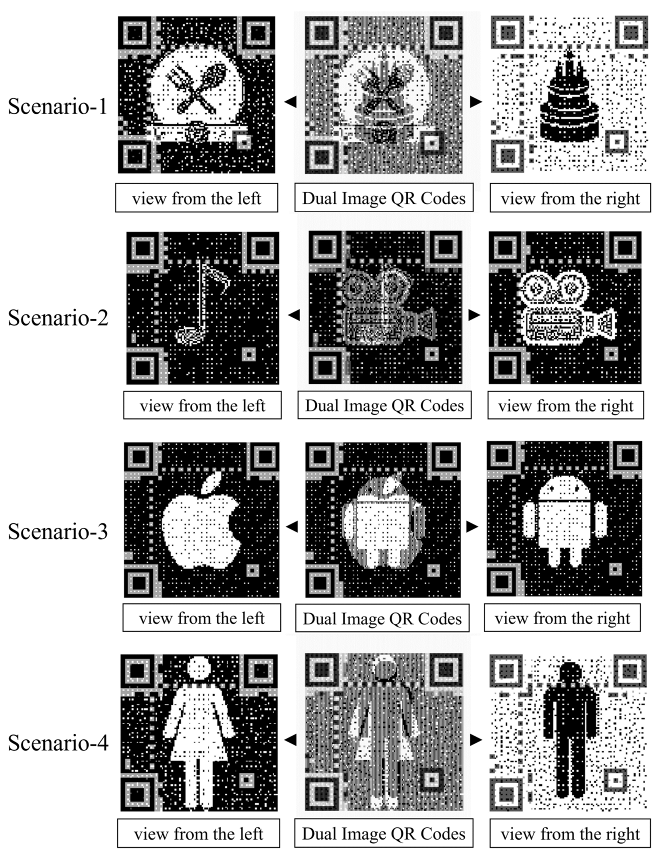

Fig. 5. Simulated scenarios used to investigate visual cues of the dual image QR codes.

VI. Discussion and Conclusion

We proposed dual image QR codes which can store two messages in one QR code and have more pleasing appearances that can give observers visual cues about what is in the code and indicate the correct scanning angle. The creation of the dual image QR code was inspired by halftone QR codes to improve appearance and lenticular imaging to increase capacity. The dual image QR codes can be decoded with standard QR code readers by scanning from the left and right angles of the QR codes when seeing the halftone QR image. We evaluated $24,000$ combinations of the QR code and extracted $3,714$ appropriate settings that achieved 100% successful scanning rate. The best input image pairs are 8-bit black background and 1-bit white background with high error correction level (ECH) and QR code version4. The best scanning condition is scanning 3inches QR codes at $40°$ from either left or right with a distance between the QR code and the scanner at 30cm. For visual perception, the dual image QR codes could effectively provide visual cues to the users.

For further work, we are investigating on improving the accessibility of the dual image QR codes by removing the lenticular lens; and we also aim to increase the capacity of the dual image by adding more message-image pairs to the QR code.

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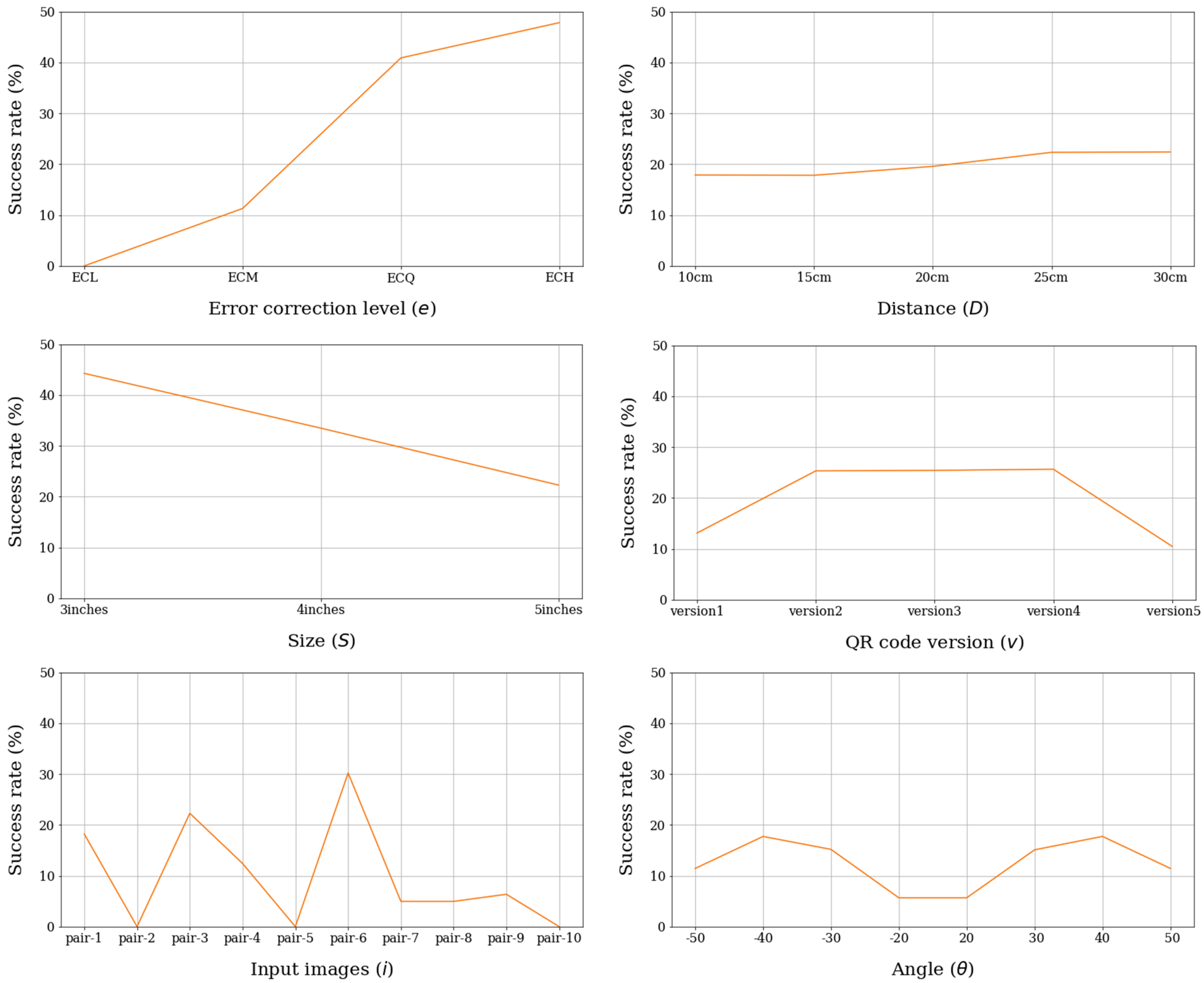

Fig. 6. The successful scanning rate of different parameters.

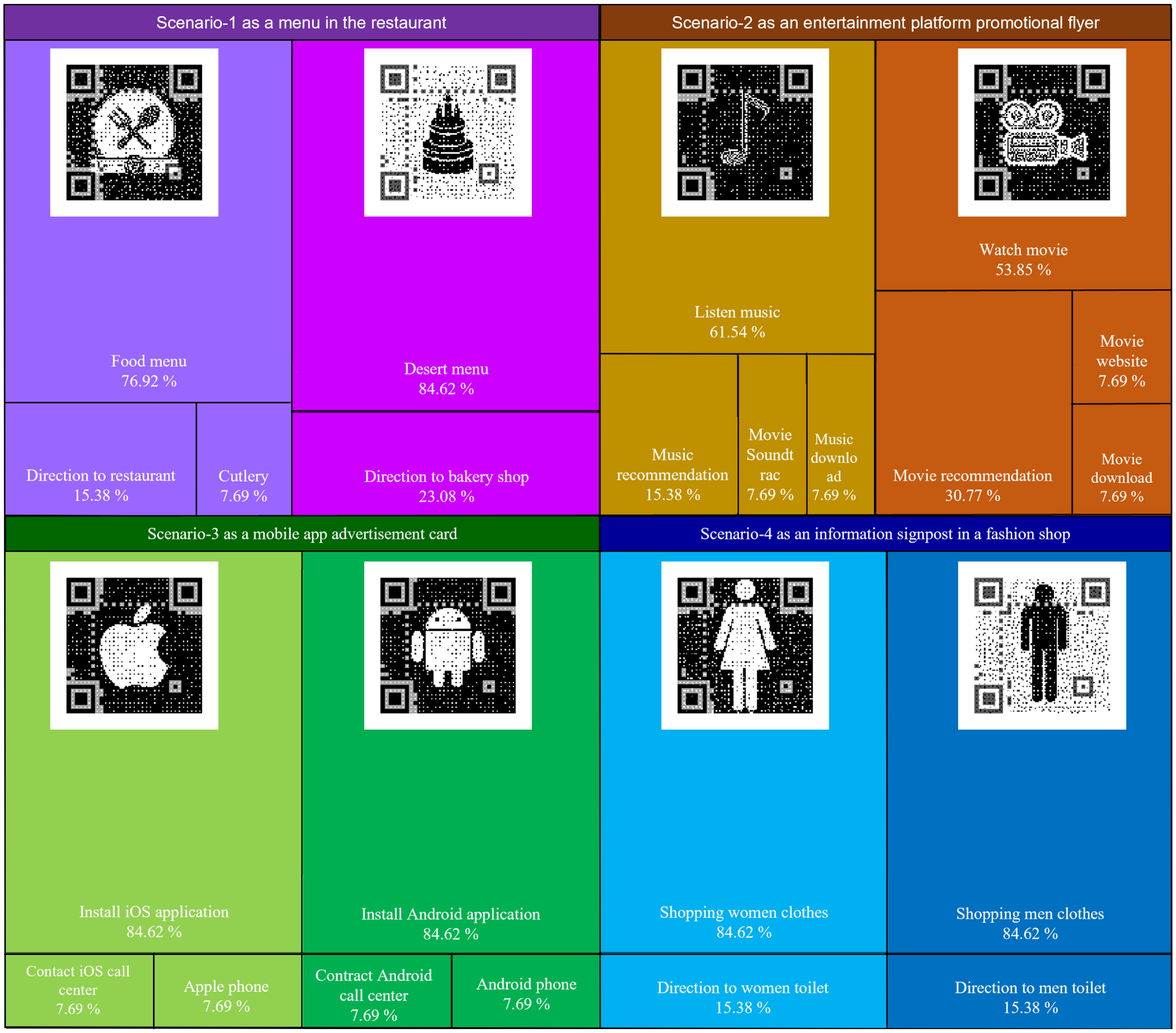

Fig. 7. The treemap shows participants' answers about the encrypted messages when the participants saw the dual QR codes' images.

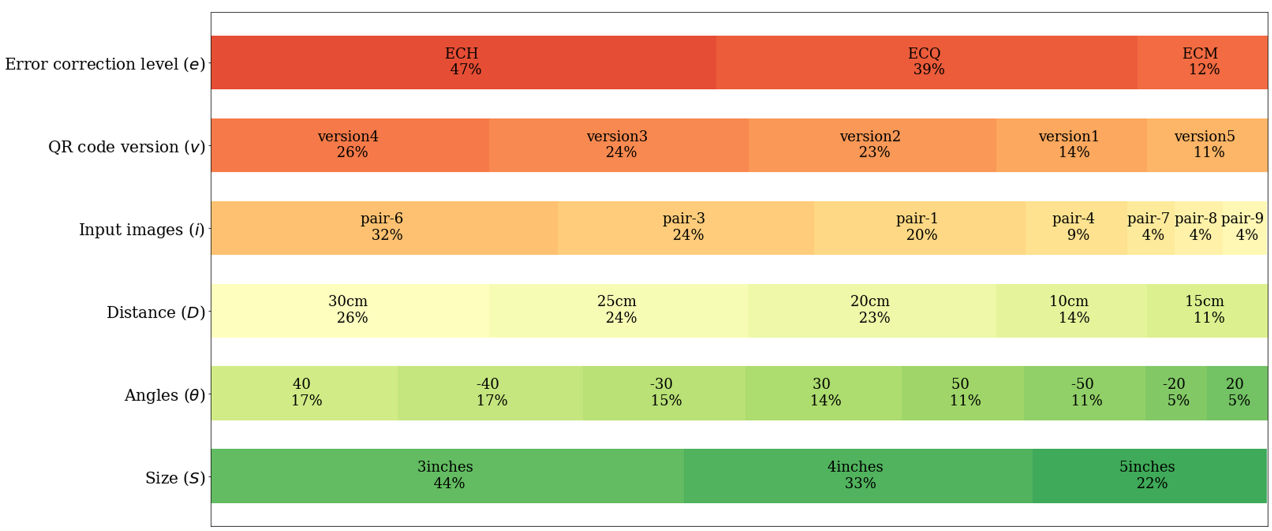

Fig. 8. Distribution of 100% success scanning rate parameters in each condition.

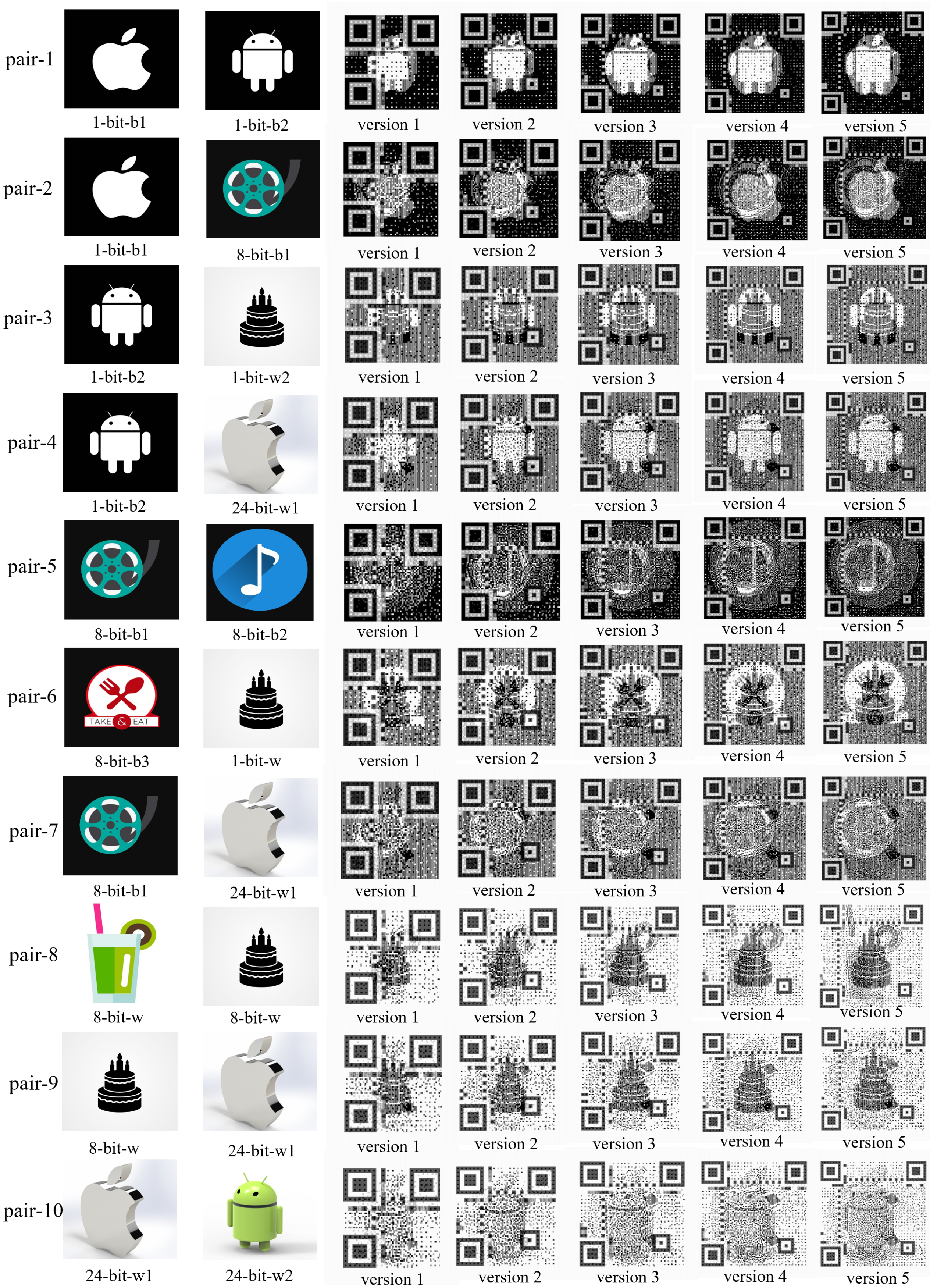

Fig. 9. Example of dual image QR codes used in the experiments. Each row shows the left image, the right image, and the fusion images versions 1-5. All 10 input image pairs are shown in the figure.