Scannability of Printed QR Codes

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Abstract

Quick Response (QR) codes are two-dimensional barcodes. They complement printed products by adding web links to a printed page. They can contain other types of information such as contact information, event information, email messages, geographical locations, and there are more ways in which they can be used. Publishers and advertisers are using QR codes to add value to static print productions, track responses to a print ad quickly, and generate additional revenues. The increase in the use of QR codes is also due to the rise in the sales of smartphones with built-in cameras, but dependent on the scannability of the printed QR codes. Most of the existing literature focuses on how to create a QR code from an on-line generator but very little literature exists that discusses how to reproduce QR codes in a small size that remains scannable.

There are many factors that affect the scannability of a QR code. In this study, five of them were tested: data amount in a QR code, code size, substrate color, printing process, and light condition during scanning. QR codes of three URL's with different characters were generated using the Kaywa Internet generator. Their sizes were varied incrementally from 0.1 inch to 1 inch. The QR codes were printed on seven substrates of different colors using offset and screen printing. Printed QR codes were scanned both indoor and outdoor using a Motorola Droid™ X2 smartphone with a built-in 8MP camera and ScanLife™ as the QR code reader. It was found that scannability of the QR codes was affected by data amount, code size, and print quality. With increasing data amount, decreasing code size and print quality, scannability went down. Substrate colors had little effect on scannability of black QR codes. Light conditions during scanning only affected scannability of QR codes printed on substrates which color appearances were more affected by the light.

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Introduction

Quick Response (QR) codes are two-dimensional (2D) matrix codes that can link print and broadcast media to a URL, share simple text data such as a phone number or a text message, or more complex information like a command. QR codes contain function patterns and encoding region so they can be scanned and decoded (Chuang, Hu, & Ko, 2010). Function patterns include quiet zone, position detection patterns, separators for position detection patterns, timing patterns, and alignment patterns. Encoding region contain format information, version information, and data and error correction code words. QR Codes have a capacity of 7089 numeric or 4296 alphanumeric characters (Gao, Prakash, & Jagatesan, 2007).

QR codes were originally developed by Japanese auto parts manufacturer Denso-Wave in 1994 for use in manufacturing to enhance inventory control (Denso-Wave, 2012). Its usage expanded to other industries, and then to consumers in Southeast Asia (Soon, 2007, and Chuang, Hu, & Ko, 2010). Consumer use of QR codes in the West occurred later, but with the rise in the sale of smartphones, the increase in the use of QR codes can be expected as well. Hulkower (2012) stated, "As of 2012, smartphones will make up 64% of mobile phone unit sales and 85% of sector revenues." Business has embraced the QR codes for use in marketing of retail products because of the ability to store large amounts of information in a small footprint. Since QR codes are becoming a more prominent and efficient form of communication between business and consumers, more QR codes will be used in print and as branding on products. A QR code can be used anywhere that a logo traditionally appears. Creative use of QR codes range from chocolate to temporary tattoos. More smartphones with different cameras possess the ability to scan QR codes dependent on the scannability of the print. Inquiries to printers in a Midwest city as well as a university print service produced no print benchmarks for scannability of QR codes. The most common response was "…if our phones can read it (QR code) then we print it" (personal communication, March 2012). Bogataj, Muck, Bracko, and Lozo (2010) found that "irrespective of the printing technique, the black printed codes are the most readable, while the yellow codes are the least readable". Most of the existing literature focuses on how to create a QR code from an on-line generator but very little literature exists that discusses how to reproduce QR codes in a small size that remains scannable.

The gap in the literature of standards for printing, size, and scannability of QR codes fueled the need to discover how small a QR code needed to be to remain scannable. There are many factors that affect the scannability of a QR code. In this study, five of them were tested: data amount in a QR code, code size, substrate color, printing process, and light condition during scanning.

Experimental

Data Amount

Three websites were selected from those readily available.

1. The Ball State University (BSU) website http://cms.bsu.edu which is 18 characters long;

2. The Department of Technology (DoT) website http://cms.bsu.edu/Academics /CollegesandDepartments/Technology.aspx which is longer at 67 characters;

3. The Graphic Arts Management (GAM) Program website http://cms.bsu.edu/Academics/CollegesandDepartments/Technology/Dept Academics/BachProg/GraphicArts.aspx which is the longest with 102 characters.

The Kaywa Internet generator http://qrcode.kaywa.com/ was used to generate QR codes for the above three URL's to test the scannability of codes with varying data amount. The three QR codes generated online were saved as jpeg files, as shown in Figure 1.

Figure 1. *QR codes for three URL's with different numbers of characters.*

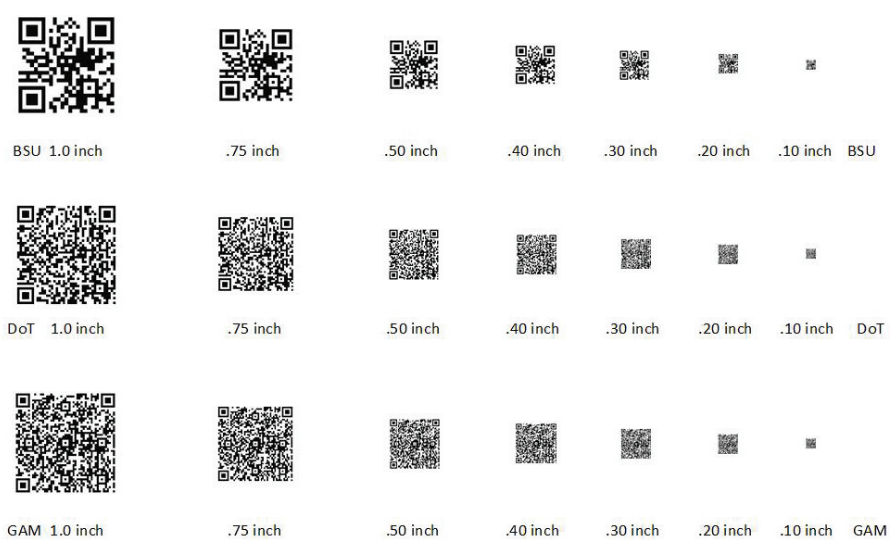


Figure 2. *Test form containing QR codes with different sizes.*

Code Size

A test form was created using Adobe InDesign CS4. It included the three URL QR codes with incremental sizes from 0.1 inch to 1 inch, as shown in Figure 2.

Substrate Color

Seven uncoated offset grade papers with different colors were selected. Their L*a*b* values were measured using an X-Rite SpectroDensitometer 528 and shown in Table 1.

Substrate	L*	a*	b*	Color
1	93.42	1.71	-5.72	
2	94.99	2.40	-6.53	
3	94.77	0.02	4.55	
4	94.88	-0.18	8.79	
5	68.72	4.59	12.74	
6	61.01	-37.89	-16.83	
7	77.55	40.59	56.40	

Table 1. *Substrate Colors*

The positions of the substrate colors relative to the (0, 0) point in the a*b* space are shown in Figure 3.

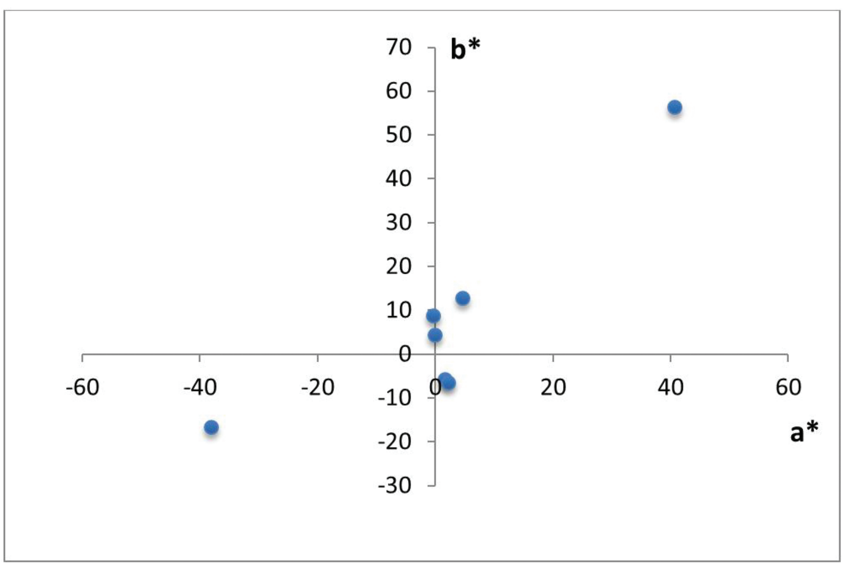


Figure 3. *Substrates' color positions relative to the (0, 0) point.*

Substrates 1-2 have small a* values and negative b* values which means they both have blue shades. Substrates 3-4 have a* values close to zero and positive b* values which means they both have yellow shades. Substrate 5 has a brown color with positive a* and b* values. Substrate 6 has a teal color with negative a* and b* values. Substrate 7 is furthest away from the (0, 0) point with an orange color and positive a* and b* values.

Printing Process

A Hamada RS 34 II press was used for offset printing with Anthem Pro™ thermal anodized aluminum plates made on Dimension™ 425 CtP system from Presstek. The screening ruling was 133 lpi with 45° angle and Euclidean dot shape.

A wood frame and Sefar mono polyester fabric of 280/inch mesh count were used for screen printing. Photographic liquid emulsion from Ulano was applied onto both sides of the screen fabric manually using a scoop coater. Positive image printed on vellum transparency using a laser printer was placed on the coated screen to expose the emulsion for 240 seconds using a 40-1K Mercury Exposure System from nuArc Company. The printing was done on a press from Vastex model V-2000 HD.

Only black inks were used for both printing processes.

Light Condition

QR codes were scanned both indoor and outdoor. Three indoor light sources came from a Color Rendition Demonstrator (GTI Graphic Technology Inc.), which were fluorescent cool-white "store light", 6500K fluorescent "daylight", and incandescent "home Light". The outdoor scans were all conducted on the same afternoon in overcast conditions.

QR Code Scanning

The best samples on each substrate were selected for the scanning test. A Motorola Droid™ X2 smartphone with a built-in 8MP camera was used along with ScanLife™ as the QR code reader. All scans were given four attempts to read before being determined to be unreadable. The goal was to find the minimum scannable size of each combination of data amount, printing process, substrate color, and light condition.

Results and Discussion

There were 7 different substrates printed by 2 printing processes so there were 14 different press sheets. There were 21 QR codes on each sheet, so there were 294 different QR codes in total. Meanwhile, because of the error correction feature of

QR codes, little differences between code qualities do not affect their scannability. Therefore, only qualitative evaluation of the print quality was performed. Offset-printed QR codes had better print quality than screen-printed ones with more uniform ink film, sharper edges, and finer details. There were little differences between different substrates.

Screen-printed QR codes had thicker ink films, thus higher optical densities than offset-printed ones, as shown in Table 2.

Substrate	Optical Density	
	Offset Printing	Screen Printing
1	1.26	1.92
2	1.44	1.90
3	1.25	2.03
4	1.31	1.93
5	1.36	1.73
6	1.29	2.02
7	1.28	1.83

Table 2. *Optical Density of Printed QR Codes*

The scannability of the three QR codes that were printed on different substrates using offset printing is represented as the minimum code sizes that could be scanned under different light conditions and shown in Table 3.

For the BSU QR code with 17 characters, fluorescent cool-white store light improved its scannability on substrates 1 and 2 which had blue shades. Incandescent home light increased the minimum scannable size of substrate 7 with an orange color. For the DoT QR code with 67 characters, fluorescent cool-white store light increased the minimum scannable size of substrate 6 with a teal color and substrate 7. Incandescent home light also increased the minimum scannable size of substrate 5 with a brown color and substrate 7. For the GAM QR code with 102 characters, fluorescent cool-white store light increased the minimum scannable size of substrates 6 and 7. Incandescent home light also increased the minimum scannable size of substrates 1 and 2. Both 6500K fluorescent daylight and outdoor daylight didn't affect the scannability of all three QR codes. Fluorescent cool-white store light has strong intensity peaks in the blue region; therefore, it might affect the color appearance of substrates with fluorescent particles which are added to increase paper brightness, like substrates 1-2. Incandescent home light has higher intensity in the yellow-red region, which might affect the color appearance of substrates with high a* or b* values, such as substrates 5-7. Color contrast between code color and substrate color is very important for scannability; therefore, these two light conditions affected the scannability of those substrates.

BSU QR Code (17 characters)				
Substrate	Store Light	Daylight	Home Light	Outdoor Daylight
1	0.2	0.3	0.3	0.3
2	0.2	0.3	0.3	0.3
3	0.3	0.3	0.3	0.3
4	0.3	0.3	0.3	0.3
5	0.3	0.3	0.3	0.3
6	0.3	0.3	0.3	0.3
7	0.3	0.3	0.4	0.3
DoT QR Code (67 characters)				
Substrate	Store Light	Daylight	Home Light	Outdoor Daylight
1	0.4	0.4	0.4	0.4
2	0.4	0.4	0.4	0.4
3	0.4	0.4	0.4	0.4
4	0.4	0.4	0.4	0.4
5	0.4	0.4	0.5	0.4
6	0.5	0.4	0.4	0.4
7	0.5	0.4	0.5	0.4
GAM QR Code (102 characters)				
Substrate	Store Light	Daylight	Home Light	Outdoor Daylight
1	0.5	0.5	0.75	0.5
2	0.5	0.5	0.75	0.5
3	0.5	0.5	0.5	0.5
4	0.5	0.5	0.5	0.5
5	0.5	0.5	0.5	0.5
6	0.75	0.5	0.5	0.5
7	0.75	0.5	0.5	0.5

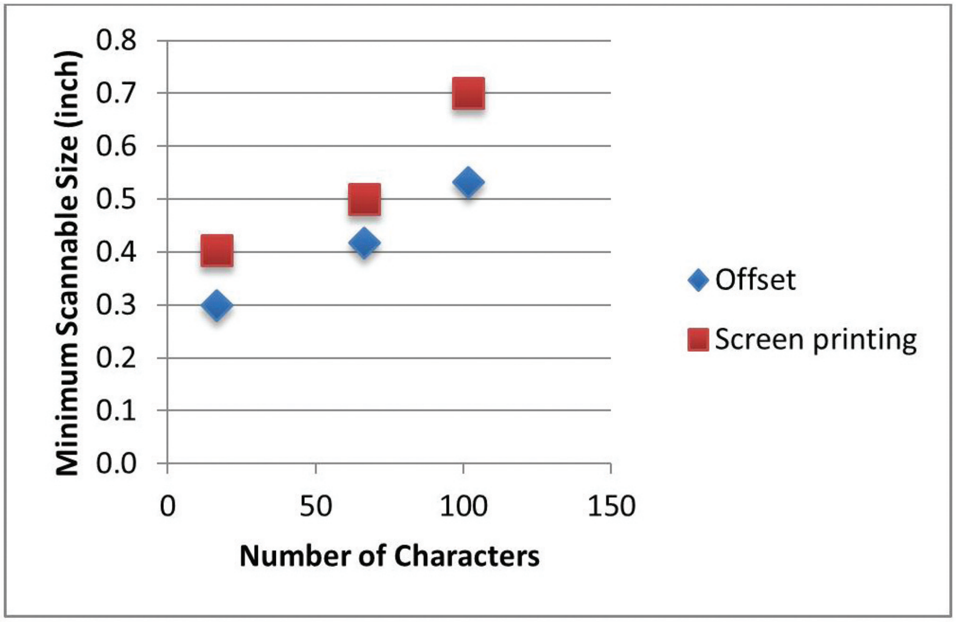
Table 3. *Minimum Size (Inch) of Scannable Offset-Printed QR Codes*

Table 4 shows the scannability of QR codes printed by screen printing. Light conditions didn't affect the BSU and DoT QR codes. Screen-printed QR codes had higher optical densities than offset-printed ones, so color contrasts between QR codes and substrate colors were higher. Small changes of substrate colors under different light conditions didn't affect QR code scannability. However, light conditions affected the scannability of the GAM QR code with 102 characters, in which there were fine details and color contrasts between QR codes and substrate colors became more important.

The scannability of QR codes printed by offset and screen printing are compared in Figure 4. With increasing number of characters in a QR code, the code size needed to be bigger in order to be scannable. For the same number of characters in a QR code, screen-printed codes needed to be bigger in order to be scannable. Although screen-printed codes had higher optical densities, thus higher contrasts between codes and substrate colors, it didn't improve their scannability. Print quality of line edges and fine details were more important factors that affected QR code scannability.

BSU QR Code (17 characters)				
Substrate	**Store Light**	**Daylight**	**Home Light**	**Outdoor Daylight**
1	0.4	0.4	0.4	0.4
2	0.4	0.4	0.4	0.4
3	0.4	0.4	0.4	0.4
4	0.4	0.4	0.4	0.4
5	0.4	0.4	0.4	0.4
6	0.4	0.4	0.4	0.4
7	0.4	0.4	0.4	0.4
DoT QR Code (67 characters)				
Substrate	**Store Light**	**Daylight**	**Home Light**	**Outdoor Daylight**
1	0.5	0.5	0.5	0.5
2	0.5	0.5	0.5	0.5
3	0.5	0.5	0.5	0.5
4	0.5	0.5	0.5	0.5
5	0.5	0.5	0.5	0.5
6	0.5	0.5	0.5	0.5
7	0.5	0.5	0.5	0.5
GAM QR Code (102 characters)				
Substrate	**Store Light**	**Daylight**	**Home Light**	**Outdoor Daylight**
1	0.5	0.75	0.75	0.5
2	0.5	0.75	0.75	0.75
3	0.75	0.75	0.75	0.75
4	0.5	0.75	0.75	0.5
5	0.75	0.75	0.75	0.75
6	0.75	0.75	0.75	0.75
7	0.75	0.5	0.5	0.75

Table 3. *Minimum Size (Inch) of Scannable Offset-Printed QR Codes*



Conclusions

There are many factors that affect the scannability of a QR code. In this study, five of them were tested: data amount in a QR code, code size, substrate color, printing process, and light condition during scanning. It was found that scannability was affected by data amount in a QR code, code size, and print quality. With increasing data amount, decreasing code size and print quality, scannability went down. Substrate colors had little effect on scannability of black QR codes. Light conditions during scanning only affected scannability of QR codes printed on substrates which color appearances were more affected by the light.

Other factors that will be further studied include different QR code colors. QR codes do not have to be standard black and white in order to be scanned. Colors and images like logos have been added in QR codes to make them more appealing, but they affect their scannability. There are also a lot of indoor and outdoor signs that use transparent film or glass with backlighting. It will be interesting to see how different backlighting affect QR code scannability. Different cell phone models and QR code readers will also be studied to find out how they affect QR code scannability.

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