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Readability of Processed Digitally Printed Two-Dimensional Codes[1]

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Abstract. *Despite the evident success of conventional one-dimensional (1D) bar codes and their role in automatic product identification, logistics, supply, and retail, these 1D technologies can encode only a limited amount of data and are susceptible to damage and obscuration. On the other hand, two-dimensional (2D) codes which began appearing in the 1980s are becoming more and more popular because of their ability to encode a large amount of data in a small area. They can also be read even if they are partially damaged or erased. Because of their advantages in comparison to linear bar codes and their increasingly frequent use the authors analyzed two 2D codes (*DATA MATRIX *code and* QR *code). The purpose of our research was to determine the lowest raster tone value for each printing color and each printing technique which would enable the 2D code reading with two different readers. For testing the readability of codes, lightfastness, accelerated aging, and water resistance were used. Codes were created and printed in four process inks (cyan, magenta, yellow and black), each of them in the following raster tone values: 15%, 20%, 25%, 30%, 50%, and 100%. Samples were printed using three different digital printing technologies (ink jet, laser, and magnetography). After printing, the samples were illuminated by Xe light, exposed to accelerated aging (at* 80°C *and 65% relative humidity) for six days, and immersed in water to determine their water resistance. All printed samples, before and after illumination and accelerated aging, were read with laser and charge coupled device based readers, and the lowest raster tone value of the code for each printing technique and each printing ink was determined.* © *2010 Society for Imaging Science and Technology.*
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INTRODUCTION

The idea of bar codes was introduced by Kermode et al. in 1934 when they published the first patent that disclosed some of the basic bar code concepts.[1] Under that patent they started marking different types of products, which provided the basis for further development of the bar code concept.[1] Conventional bar codes gained wide acceptance in applications ranging from checkout and inventory control in retail sales to tracking printed circuit board serial numbers in electronics manufacturing. To increase the character content and to store the information in smaller spaces, companies have developed two-dimensional solutions. Two-dimensional (2D) bar codes were developed, placed in the public domain and published as AIM standards in 1987.[2] A 2D code stores information along the height as well as the length of the symbol.[3] Consequently the size of 2D code is smaller than a conventional bar code with same data encoded. Besides larger capacity than bar codes, 2D codes also have an error corrector included. To ensure accurate reading, 2D codes use the Reed-Solomon codes.[3] In addition to the conventional applications known for bar codes, 2D codes found new areas of application. Nowadays they can be found in different areas such as advertising, mobile learning and direct part marking. The development and standardization of 2D codes are promoted by different entities; GS1 Mobile Com group and Open Mobile Alliance are two of them. They are focused on growth of the market for the entire mobile industry by removing barriers to interoperability, supporting a seamless and easy-to-use mobile experience for users, and a market environment that encourages competition through innovation and differentiation.[4]

Not a lot of research has been done in the field of 2D code readability. In the article entitled "Investigation of the potential use of e-tracking and tracing of poultry using linear and 2D bar codes,"[5] the authors assessed a procedure for the application of DATA MATRIX (DM) codes onto poultry by ink jet printing. The readability, standard error in readability, and reading time were calculated. Billo and coauthors in their paper[6] describe a standard testing methodology to objectively compare the performance of a new class of two-dimensional bar codes for an overhead sorting and tracking application in an automated material handling environment.

The successful use of such a code requires the reading of the code at both high speed and accuracy. One of the most important factors for good and fast code reading is their good print quality and the use of black ink on a bright matte

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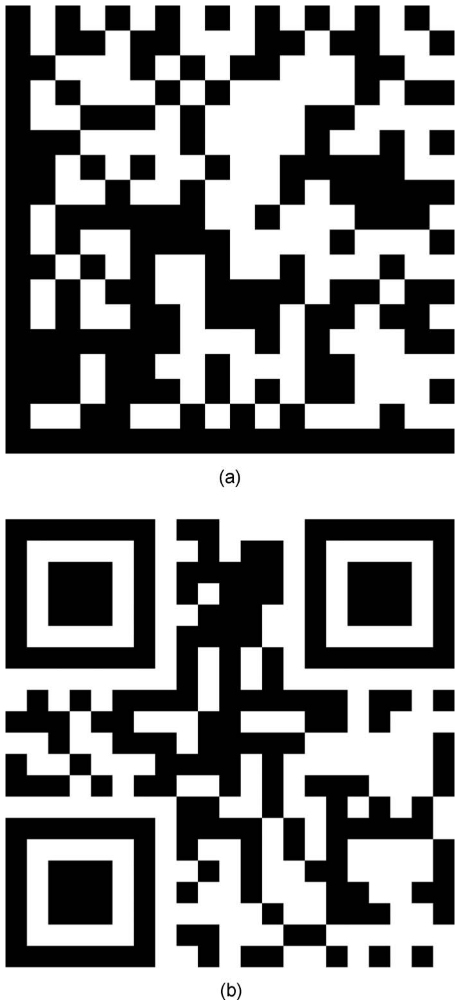


Figure 1. DATA MATRIX (a) and QUICK RESPONSE (b) code.[11]

printing substrate. But, in some cases, the mentioned limitations may have a negative effect on the end product design and image.

The purpose of the present research was to investigate the effect of different ink colors, different raster tone values, and different digital printing techniques on the ultimate code readability, additionally influenced by lightfastness, accelerated aging, and water fastness tests. In addition, the difference between two types of 2D codes was explored as well.

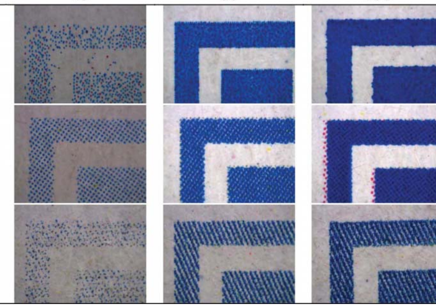
EXPERIMENT

Two types of 2D codes were used in the study, DATA MATRIX[7] (DM) and QUICK RESPONSE (QR),[8] as shown in Figure 1.

DM code[7] is a 2D matrix code designed to pack a lot of information in a very small space. Maximum data capacity of a symbol of 144 square modules is 3116 numeric digits or 2335 alphanumeric characters. The most popular application for DATA MATRIX is the marking of small items such as integrated circuits and printed circuit boards. These applications make use of the code's ability to encode approximately 50 characters in a 2 or 3 mm^2 symbol and the fact that the code can be read with only a 20% "contrast" ratio.[9]

Table I. Images of different raster tone values (dot raster pattern) for each printing technology. Capturing was done with optical microscope Leica EZ4D at 20× magnification.

Printing technology	Raster tone value [%] 15	50	100
Ink jet			
Laser			
Magnetography			



QR code[8] is a matrix code developed by Nippondenso ID Systems and it is in the public domain.[3] QR code holds up to 7089 numeric characters which is 10–100 times as much information per unit area compared to the bar code. QR code has a built-in capability for interpolating data correctly from code patches that are dirty or damaged.[10] QR code is designed for rapid reading using charge coupled device (CCD) array cameras and image processing technology due to the layout of the finder pattern.[3]

The present study was divided in two parts. In the first part, the effect of printing ink color and its raster tone value on 2D code readability was investigated. The codes were printed by three digital printing techniques and the smallest raster tone value for successful reading for each of the printing techniques was determined.

In the second part of the study the readability of 2D codes was investigated after their exposure to light accelerated aging and to the water resistance test.

For reading evaluation two different types of readers were used: one based on conventional laser technology and the other on modern CCD sensor technology.

Generating and Printing

The encoding of information was done by freely available online generators.[12,13]

Two different codes with module size of 1×1 mm were generated as follows: DM code and QR code.

The same URL address "www.valkarton.si" was encoded in both 2D code types.

Both codes were printed in four process colors: cyan, magenta, yellow, and black (CMYK). To define the limited readable raster tone value, a test form with codes of different raster tone values (15%, 20%, 25%, 30%, 50%, 100%) for each color was designed as shown in Table I. As printing substrate, the packaging cardboard Reno de Medici 230 g/m^2 (Italy) was used.

To determine the influence of digital printing technologies on the end code readability, three different printing machines were used; besides the widespread ink jet and laser printing techniques, magnetography was used as well. Magnified images from all printers at different raster tone values are shown in Table I.

Table II. Illumination conditions.

Radiation intensity	$E=42\ W/m^2$
Number of phase	1
Time of one phase	60 min
Chamber temperature	CHT = 35 °C
Black standard temperature	BST = 50 °C
Relative humidity	RH = 35%
Manner of illumination	Turning mode
Filter	Xenochrome 320
Total time	72 h

The printing conditions for all techniques were as follows:

- Ink jet printing (Ink jet); HP DeskJet 5652 printer for plain paper and normal print quality preferences and maximal resolution 1200 × 1200 dpi.
- Laser printing (Laser); HP Color LaserJet 3550 laser printer with default settings at plain paper preference and resolution 600 × 600 dpi.
- Magnetography printing (Magnetography); Oce 700 printing machine at 230 g/m^2, coated paper preferences and resolution 400 × 600 lpi.

Reading

The printed samples were read by two readers based on different technologies:

1. Symbol DS 6607 reader that illuminates with 650 nm laser diode (hereinafter called the laser reader) and 640 × 480 ppi resolution.
2. Symbol MC9090-G RFID reader which captures the codes with a CCD sensor with limited resolution 640 × 480 ppi, hereinafter called the CCD reader.

For reading measurements all samples were exposed to standard daylight in The Judge II (Gretag Macbeth) chamber and illuminated at a 45° angle. The smallest raster tone value for each code that the reader still can read was determined. Each sample was read ten times and the results of 2D codes readings were divided in two classes: (1) readable codes if the reading was successful at least eight times and (2) unreadable codes if the reading was successful less than eight times.

Lightfastness (Xe)

Products with codes printed on their surface are often exposed to the influence of sunlight, in particular in packaging applications. Therefore the 2D codes were exposed to artificial light (illumination by Xe lamp, Table II) simulating sunlight and enabling an accelerated aging test. An hour of the exposure of samples under Xe light is taken as comparable to 10 h of daylight, i.e., one day; thus a 72 h of lightfastness test represents an exposure of samples to 72 days of daylight.

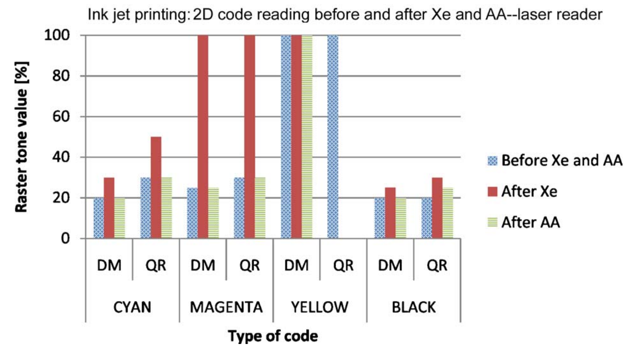


Figure 2. The lowest raster tone value which enables code reading before and after Xe and AA.

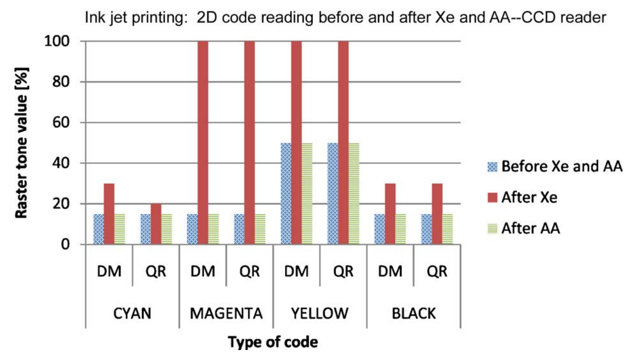


Figure 3. The lowest raster tone value which enables code reading before and after Xe and AA.

The testing was performed using a Xenotest Alpha (Atlas, USA) source in accordance with ISO 12040 standard.[14]

After the lightfastness test the lowest raster tone value at which the 2D codes could be read was determined again.

Accelerated Aging (AA)

A six-day artificial aging of samples in moist air, 80 °C, and 65% relative humidity, was carried out. Aging was performed in accordance with ISO 5630–3:1997 standard.[15] After accelerated aging the readability of 2D codes was determined again.

Water Resistance

Samples of 2D codes printed at the 100% raster tone value were completely immersed into deionized water for 24 h. After that, samples were loaded with 1 kg for 10 min and dried in accordance with ISO 11798:1999 standard.[16] The readability of codes was determined before and after immersion into water.

RESULTS AND DISSCUSION

The first part of the investigation focused on determination of the lowest raster tone value for each process color printed by the two different printing techniques. In the charts below (Figures 2–7) the results for each printing technique and both types of readers are presented.

Lightfastness and Accelerated Aging

Ink Jet Printing

The best results were achieved for the black printed codes before Xe and AA as shown in Fig. 2. The reader can

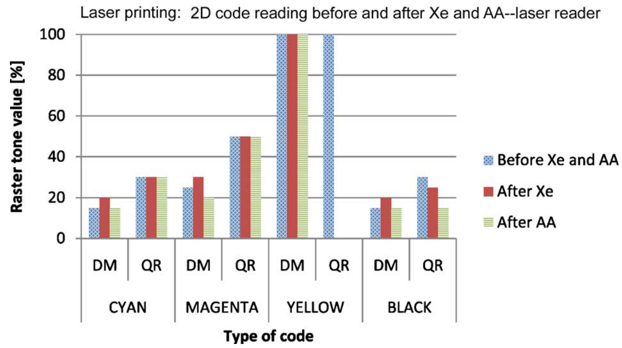


Figure 4. The lowest raster tone value which enables code reading before and after Xe and AA.

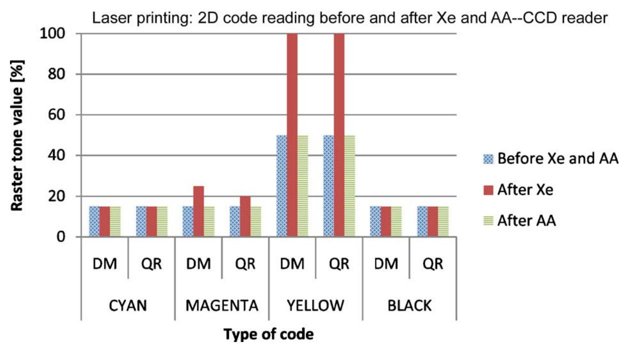


Figure 5. The lowest raster tone value which enables code reading before and after Xe and AA.

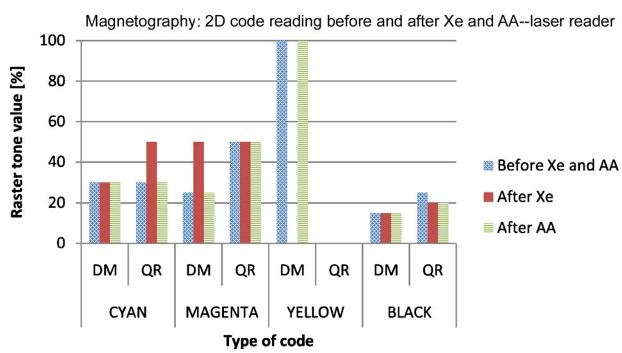


Figure 6. The lowest raster tone value which enables code reading before and after Xe and AA.

read black DM codes at only 20% of raster tone value. The readability of cyan and magenta codes is lower than that of the black codes. Yellow ink is inappropriate for codes printing as its raster tone value is too low. The results in Fig. 2 also show that DM codes provide better readability than QR codes in all cases.

After irradiation (Xe), the readability of codes diminish for all printing inks but nevertheless the black codes still show better readability than the other colors, particularly yellow. The most obvious degradation in readability was measured for magenta printed codes. Accelerated aging of ink jet printed codes does not cause major changes, so the readability of all CMYK printed codes remains mostly unchanged.

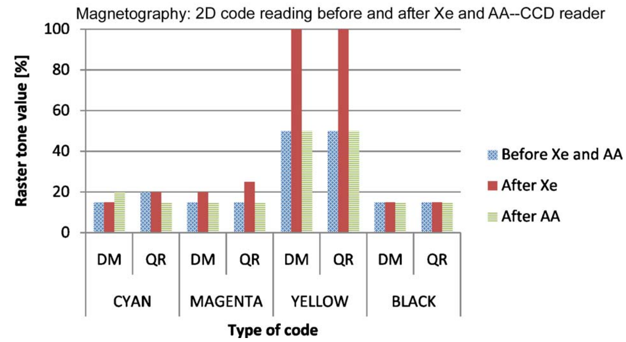


Figure 7. The lowest raster tone value which enables code reading before and after Xe and AA.

With respect to the readers, the results of reading with the CCD reader are much better than those of the laser reader (Fig. 3). In general, the codes before Xe and AA as well as after AA are read at lower raster tone values with CCD reader than with the laser reader.

Laser Printing

As shown in Fig. 4, the black codes printed by the laser printing technique are the most readable, before and after Xe and AA. Cyan printed codes are readable at only 15% except after Xe irradiation. The same occurs for magenta DM codes. Yellow codes are not readable even at 100% raster tone value. The comparison between DM and QR readings shows that DM codes have better readability at lower raster tone values. The results of reading codes before and after Xe as well as before and after AA deviate much less for ink jet printed codes, which provide better resistance to light, heat and humidity than laser prints.

The results achieved after AA show that the codes have the same or even better readability than before AA. Cyan, magenta, and black printed codes are readable at 50% raster tone value or lower, while yellow is readable at 100% raster tone value. Degradation of surface characteristics of the printing substrate during AA might cause the higher "contrast" between printing ink and printing substrate and consequently better reading results.

Similar to ink jet prints, laser prints provide better reading results at lower raster tone values with the CCD camera than with the laser reader. For black and cyan printed codes, the raster tone value of only 15% was sufficient for reading while magenta required a bit more. Yellow printed codes were readable at a raster tone value of 50% in all cases except after Xe (Fig. 5).

Magnetography

The 2D codes printed by magnetography appear to be lower in quality in comparison to other tested printing techniques; yellow printed codes are unreadable even at 100% raster tone value (Fig. 6).

As already measured for ink jet and laser prints, the CCD reader also enables better reading results than the laser reader for magnetography prints; the 2D codes are readable at lower raster tone values with the CCD camera than with the laser reader (Fig. 7). Black printed codes require only 15% raster tone value for reading and cyan and magenta

Table III. Results of 2D code (at 100% A) readability before and after immersing into water; 1: readable codes; 0: not readable codes.

		Ink jet		Laser		Magnetography	
Printing ink	Before/after immersing	Laser	CCD	Laser	CCD	Laser	CCD
Cyan	Before	1	1	1	1	1	1
	After	1	1	1	1	1	1
Magenta	Before	1	1	1	1	1	1
	After	0	0	1	1	0	1
Yellow	Before	0	1	0	1	0	1
	After	0	0	1	1	1	1
Black	Before	1	1	1	1	1	1
	After	1	1	0	0	1	1

printed codes around 20%. Yellow printed codes require 50% raster tone value before Xe and AA as well as after AA. After Xe, 100% raster tone value is required for reading the yellow printed codes.

Comparison Between Laser and CCD Reader Results

The important difference between the CCD reader and the laser reader is that the CCD reader measures emitted ambient light from the bar code whereas laser readers measure reflected light of a specific frequency originating from the reader itself.[17] As already discussed, laser and CCD readers obtain different reading results with the same code under the same measuring conditions. The CCD reader can read 2D codes at much lower raster tone value than the laser reader for all colors (CMYK) as well as for all printing techniques and all types of 2D codes included in the study. The major difference between the two readers is detected for yellow printed codes, but the difference is also noticeable for magenta printed codes. The CCD reader is capable of reading the magenta, cyan and black printed codes even at only 15% raster tone value. The same results were achieved for the readings after AA (Figs. 3, 5, and 7). The results for reading after Xe show that higher raster tone values are required even for reading with the CCD reader but still less than for reading with the laser reader, particularly for laser and magnetographically printed codes (Figs. 2, 4, and 6).

Water Resistance

For measuring water resistance, all printed samples with 100% raster tone value (100% A) were immersed into deionized water as described in the experimental part. After the water resistance test, the readability of the samples was determined. The durability of printing ink exposed to water can be explained by the complex influence of the test method that involves not only the immersion into water, but the load as well. During the load of 1 kg for 10 min, a number of prints were damaged, the adhesion between printing ink and printing substrate diminishes and some small parts of printed codes were removed from the print, disabling the reading. As shown in Tables III and IV the best results for reading were achieved with the CCD reader, which was capable of reading more codes than the laser reader.

Table IV. QR Code images (with 100% raster tone value) after immersing into water.

Printing ink	Before/after immersing	Ink jet	Laser	Magnetography
Cyan	Before			
	After			
Magenta	Before			
	After			
Yellow	Before			
	After			
Black	Before			
	After			

Table III shows that the cyan printed codes have the best readability before and after immersing in water; very good results were obtained for black printed codes. The worst results were obtained for magenta printed codes.

CONCLUSIONS

As the code reader works on the basis of absorbed or reflected light from the code, the raster tone value, the contrast between the printed code and substrate, is crucial for code reading. If we print with process printing inks without yellow we get satisfactory readability even at low raster tone values (30%). On the other hand, if we use yellow printing ink we have to print at 100% raster tone value or, even better, abolish the yellow color altogether. However, the CCD reader is capable of readings at lower raster tone value than the laser reader, as proved for all printing techniques and for all printing ink colors irrespective of the type of 2D code, DM or QR.

Ambient illumination may have an impact on the contrast between print and substrate. Exposure of 2D codes to Xe illumination proves this. On the other hand, accelerated aging shows almost no influence on the reading contrast, as proven by both reader types. Consequently, there are no effects on code readability when codes are exposed to high humidity and temperature. Irrespective of the printing technique, the black printed codes are the most readable, while the yellow codes are the least readable. Water resistance test has shown that 2D codes can be damaged and accordingly become less or not at all readable. This test proved that the cyan samples printed by all three printing techniques were the most readable after immersion in water.

Besides the fact that the black printed 2D codes will show the highest contrast against the printing substrate and therefore the most readability, this article has proven that the required reading contrast can be achieved with other colors, specifically cyan or magenta, and that greater attention should be given to the printing technique and to the exposure of the 2D codes to light or water.

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