Barcodes versus matrix codes: an experimental comparison of recognition quality from mobile phone camera photos.

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Abstract. The dynamic nature of shopping requires price comparison services for mobile platforms to make the provision of product information to these services as convenient and reliable as possible; thus, barcode scanning is typically introduced to such systems. Still, the linear barcode is not easy to read by mobile phone cameras, especially in a setting where a large variety of hardware may be employed. This paper presents a more recent matrix code standard, and compares it to linear barcodes in terms of encoded information and provided safety mechanisms. Finally, an experiment is conducted on a variety of mobile phones in order to establish how well each type of code is decoded in practice.

Key words: barcode, matrix code, mobile device, image recognition

1 Introduction

There are a number of uses for barcodes, whether in the common and well-known one-dimensional form or the two-dimensional matrix form. This is especially true in conjunction with the growing popularity of mobile devices, which can benefit from a quick way to extract information from real-world objects. Uses for various types of codes span from implementation of augmented reality systems [16, 9, 18, 17] through security and authentication mechanisms [4, 12, 10] to service discovery via barcodes on posters [15, 14].

In particular, the modern world presents an opportunity for barcodes to be used in price comparison services. Shopping can be a dynamic experience where a person may encounter a product on a store shelf of which he or she was previously unaware, and such that the person will immediately become interested in obtaining. With the use of the Internet, a similar find could be compared with other products, or the same one available from other retailers, in terms of price, warranty, and whatever other conditions the shopper is interested in. Indeed, a number of services are available that automate the process of online product comparison. Such comparison, however, is hindered when shopping off-line: the shopper is limited by location and time—he or she may be interested only in products within a certain distance (thus further complicating the already-difficult optimization problem [11]) and is likely to avoid spending a long time on providing a description of a specific product to a service. In addition, many brick-and-mortar stores are typically unavailable for comparison via existing services.

Some of these obstacles may be well solved by barcodes in the role of identifiers linking digital information about an object—the price, and other qualities that consumers are interested in comparing—with the actual physical object that information describes. In other words, a barcode may serve as the object's unique identifier, regardless of the store in which it is sold (indeed, this is true for products registered with GTIN [3]) and a shopper would be able to use this identifier, possibly along with his or her location information, to perform a comparison of offers on the same or similar objects in a number of brick-and-mortar stores.

However, our previous experiments with such a solution proved that mobile phones available at the time were incapable of taking pictures of barcodes of high enough quality for their content to be read [20]. In this paper we explore to possibility of using a different type of visual code to encode product information in order to avoid the problems we have identified thus far.

This paper is structured as follows. After a brief introduction in Section 1 we describe a common type of barcodes used in product identification, and a common type of two-dimensional code in Section 2. Then we describe our experiment that is meant to compare the effectiveness of scanning barcodes in comparison with two-dimensional codes and present its results in Section 3. Finally, we interpret the results of the experiment in Section 4.

2 Barcodes and matrix codes

Barcodes are standards for encoding information into a series of bars and spaces in a one-dimensional pattern used for data representation since its conception in 1949 by Bernard Silver and Norman Joseph Woodland. Matrix codes extend the original idea behind barcodes to an improved two-dimensional design.

Both sorts of codes are diversified by a number of standards and families of standards. The EAN and JAN (Japanese Article Number) families of barcodes, and UPC (Universal Product Code) can be counted among the most popular barcode standards. QR code, Aztec code, CyberCode, and Datamatrix, among others, are common two-dimensional codes. This section briefly describes EAN-13 and QR code—popular standards for visual codes.

2.1 EAN-13

EAN-13 (International Article Number, originally European Article Number) is a 13-digit barcode standard used throughout the world to identify products (EAN-13 is one of the standards supported by GTIN, along with its 12-digit subset, UPC). Logically, EAN-13 barcodes consist of four basic components: a prefix indicating the country of origin (a GS1 prefix [2]), a company identifier, an item reference unique to the company, and the last digit is used as a check sum.

The bars on the code are placed in two groups of six pairs, each pair representing a digit (the check sum is not encoded as bars). The groups are separated by a dividing bar, and similar bars are placed on each side of the barcode—these are meant to help to orientate the scanner. There digits are translated into bars using one of three types of encoding. The six digits in the rightmost group are represented uniformly using R-encoding, while three of the leftmost group use L-encoding and three use G-encoding. The precise application of encoding depends on the first digit of the barcode, and is implemented in order to provide an extra error-detection mechanism. The entirety of the code needs to be surrounded by a quiet zone—an empty space around the barcode that allows a scanner to locate the bars.

2.2 QR code

QR code (Quick Response Code) developed by Denso-Wave, is among the most popular types of two-dimensional codes used for encoding digital information in a wide variety of contexts from plain text, through e-mail addresses, to geolocation information. A number of *de-facto* standards for encoding the various types of information in the matrix have been introduced.

A QR code matrix consist of a number of required patterns placed among the data: three square patterns in the corners of the barcode connected with leads signifying the position of the code, a differently-sized square pattern in the remaining corner for alignment, two rectangular areas with version information, and format information in the vicinity of position patterns. The remainder of the matrix (a total of 2953 bytes) is used for data interleaved with error correction bits. The various checks included in the matrix are used by the scanner to properly rotate and align the code before scanning, and the other control information prevents errors and aids recovery [13].

3 A comparison of code recognition effectiveness

The following section describes our experiment in barcode and matrix code recognition: our goals, the procedure we used, software and hardware used in the experiment, and finally, our results and conclusions.

3.1 Goals

The goal of this experiment is to study and compare the effectiveness of scanning barcodes and their two-dimensional counterparts—data matrices—obtained from various mobile phone cameras. The effectiveness of recognition weighs on whether the codes can be used in the contexts described in the previous section. We consider this effectiveness to be a measurement of the code types' quality.

We assume the quality of a code can be inferred from two facts: If one type of code can be recognized successfully from smaller photograph images than another type of code, then that one type of code is of superior quality to the other. In addition, if one type of code is recognized correctly more frequently than another type of code, then that one type of code is superior.

We postulate that the quality of scanning of two-dimensional codes surpasses that of scanning one-dimensional barcodes. Thus, an experiment was conducted in order to test this hypothesis. We specify the following criteria for barcode quality:

1. It is asserted that the quality of scanning is positively correlated with the minimum size of a code that can be successfully processed. Therefore, the main quality indicator will be the mean size (width) of a code that can be recognized by various cameras, for both one-dimensional and two-dimensional codes.
2. Additionally, a supporting quality indicator will be the probability of recognizing a code—a ratio of the total number of correctly recognized codes to the total number of attempted images for each type of code (see). Such a test represents a success rate in a situation where a diversified group of users (with different mobile phones) would require scanning codes found on a large set of products, differing in sizes and types.

3.2 Procedure

The code types used for the procedure are EAN-13 and QR codes, which are among the most common types of one-dimensional and two-dimensional codes (respectively). Apart from their popularity, the advantages to choosing these types of codes include the existence of number of tools both for generating and recognizing them.

Instances of the two selected code types were generated containing an arbitrary numerical content with the sizes in pixels and millimeters are presented in Table 1. The range of sizes used for the experiment was chosen by identifying the range variety that can be expected to be used for marking everyday products in stores (between 13 and 40 millimeters in width[1]). The range was then extended up to 58 millimeters to allow for a margin, and eight discrete sizes were selected for testing from it. After an initial test, additional 66, 80, and 108 millimeter EAN-13 barcodes were added to allow the less-capable device cameras to be placed in the results. This was not necessary for QR codes. Examples of the EAN-13 and QR codes generated for the experiment are shown in Figure 1 [2].

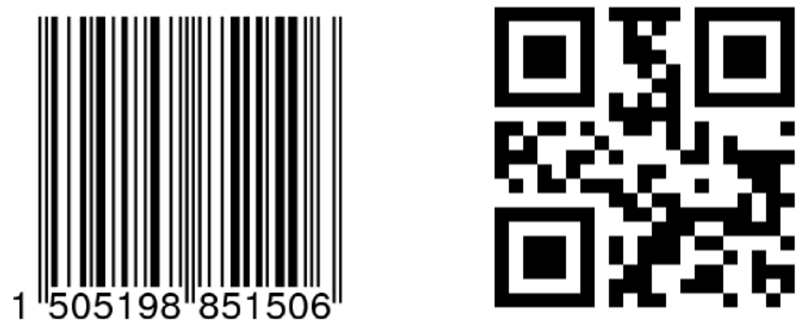
As the next step, the nineteen generated code instances (8 QR and 11 EAN-13 codes) were displayed on a LED screen (with back-light illumination) and photographs of each of the generated codes were taken with a number of mobile

[1] The barcodes include a quiet zone—a surrounding white space required for processing by a scanner.

[2] All codes generated for the experiment are available at [6].

	Size (width)											
	80	120	160	230	250	280	320	350	400	500	600	[px]
	13	19	26	36	40	46	52	58	66	80	108	[mm]
EAN-13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
QR	✓	✓	✓	✓	✓	✓	✓	✓				

Table 1: Code sizes used for the experiment.



(a) EAN-13 Barcode (b) QR Code

Fig. 1: An example of codes generated for the experiment. Both specimen are 250 pixels (40 millimeters) wide and hold the same data.

phone cameras that were available to the authors. It was also noted, if any cameras failed to take photographs of the provided codes due to a failure to focus the lens (i.e. the device disallowed the picture to be taken at all due to focusing problems).

The conditions for taking photographs of codes were prepared with care to prevent any of the problems we described in [20], i.e.

- the users' lack of experience in taking photos of small objects, resulting in bad focus, cropping, skew, or causing motion blur,
- lighting conditions causing reflections on the surface of the generated code,
- insufficient light causing the contrast between the code and its surface to be insufficient for recognition,
- convex, concave, or irregular surfaces introducing perspective distortion to the photographed code.

Finally, the photographs were collected [6] and scanned using the software described in the following section. The scanning procedure itself consisted of scanning each photographed code in an attempt to recognize its content. The first attempt at scanning was conducted on the original images received from mobile devices (with the resolution of at least 1280×1024 pixels. However, we found that recognition performs better with smaller images, so we added an adaptive resizing module to the procedure, which resized each image to the resolution of 350×280 pixels prior to scanning. We also attempted applying sharpeningand contrast-enhancing modules to the procedure, but no they effected in no significant improvement, so their use was abandoned.

3.3 Software tools

JBiedronka [8] is a Java application developed at the Poznań University of Technology as a desktop program intended as a front-end to a barcode scanning library, and furnished with a set of optional filters that could improve the effectiveness of recognition.

The program was adapted from the original version to better fit the current experiment. Primarily, the program now uses the ZXing [21] library for barcode recognition, replacing the the J4L RBarcode Vision [7] library. This change was decided on the fact that the latter is able to process both one- and two-dimensional code formats, whereas the former, in the form utilized up to this point, is limited only to one-dimensional barcodes. Additionally, Zxing has the following advantages:

– the library provided support for a range of one- and two-dimensional code types most commonly used throughout the world for coding information about commercial products (in particular, the EAN and UPC families endorsed by GTIN) and the most common types of two-dimensional barcodes;
– the development focuses on interoperability with mobile phone cameras;
– the library undergoes active development;
– the library is open source.

In addition to the change of back-end, an adaptive-resize module was added to the already existing contrast- and sharpness-enhancing modules, all implemented using ImageMagick [5]—a portable, open-source solution with a command-line interface allowing execution of bulk operations.

A number of additional software tools were used apart from the modified JBiedronka. Barcodes generated for the purposes of the experiment were created using two software applications: the one-dimensional EAN-13 barcodes were created using GNU Barcode [1], and the two-dimensional QR Codes were generated using the QR Code Generator from the ZXing Project. Finally, SPSS (formerly known as the Statistical Package for Social Sciences) [19] is used to conduct the statistical analyses necessary to interpret the results of the experiment.

3.4 Examined hardware

A certain spectrum of mobile phone cameras was used in the experiment, ranging from high quality high-resolution models with adjustable lenses (with macro photography functionality, or the ability to autofocus) to low-end models with fixed lenses and lower resolutions. The selection of particular models was also influenced by availability at the time of data collection. All cameras were equipped with stock camera software, as provided originally by the retailer.

The list of tested mobile phones and the characteristics of their cameras is presented in Table 2.

Device	Camera resolution [pixels]	Picture resolution [megapixels]	Focus type
Apple iPhone 3G	1600×1200	2.0	fixed lens
HTC T-Mobile G1	2048×1536	3.3	autofocus
Nokia 6233	1600×1200	2.0	fixed lens
Sony Ericsson G502	1600×1200	2.0	fixed lens
Sony Ericsson K310i	1280×960	0.3	fixed lens
Sony Ericsson K510i	1280×1024	1.3	fixed lens
Sony Ericsson K600i	1280×1024	1.3	fixed lens
Sony Ericsson K750i	1632×1224	2.0	autofocus
Sony Ericsson K850i	2592×1944	5.0	autofocus, macro
Sony Ericsson T280i	1280×1024	1.3	fixed lens
Sony Ericsson W610i	1600×1200	2.0	autofocus

Table 2: Telephone device picture-taking capabilities.

3.5 Results

The results of code recognition for both QR and EAN-13 codes are presented in Table 5. In the top part of the table each row represents the results of code recognition for a single model of a mobile phone. The columns list the size in pixels and type of code of each scanned image. The cells are marked as follows:

- A cell is marked with a check mark (✓) if the image of a code of the type and size specified by the column, taken with a mobile device specified by the row, was successfully recognized by the application;
- A cell is left blank if the given image was not recognized by the application (scanning did not produce a results).
- A cell is marked with a dotted circle (⊙) if the mobile device was not able to focus on the given image to take a photo. Effectively, we treat this situation as equivalent to the image being unrecognized by the application.

The bottom part of table presents the sums of correctly recognized codes, unrecognized codes, and codes that devices could not focus on, for each type and size of code. Finally, the ratio of correctly recognized codes to all attempts of scanning a given size and type of code is given.

Mean minimum recognized code size

In order to confirm our hypothesis that the QR codes are recognizable at a smaller size than EAN-13 , we compare the smallest sizes of codes scanned by various devices. The minimum recognized size of code for each phone, selected from the results, is presented in Table 3. The table also aggregates the results partially by providing the maximum, minimum, and mean values, and the standard deviation.

The hypothesis and null hypothesis follow:

Device	QR Code		EAN-13	
	[px]	[mm]	[px]	[mm]
Apple iPhone 3G	160	26	600	108
HTC T-Mobile G1	160	26	600	108
Nokia 6233	160	26	500	80
Sony Ericsson G502	230	36	400	66
Sony Ericsson K310i	120	19	280	46
Sony Ericsson K510i	230	36	600	108
Sony Ericsson K600i	230	36	600	108
Sony Ericsson K750i	120	19	350	58
Sony Ericsson K850i	280	46	600	108
Sony Ericsson T280i	80	13	160	26
Sony Ericsson W610i	230	36	160	26
Minimum size	80	13	160	26
Maximum size	280	46	600	108
Mean size	181.92	29.91	440.91	76.91
Standard deviation	61.92	9.99	179.91	34.23

Table 3: Mean minimum recognized code sizes per device.

Hypothesis: the mean of minimum sizes of scanned QR codes is lower than the mean of minimum sizes of scanned EAN-13 codes.

Null hypothesis: the mean of minimum sizes of scanned QR codes is statistically equal to that of scanned EAN-13 codes.

We attempt to establish the correctness of these hypotheses by employing a Student's t-test. The presented data set is paired, therefore a Student's dependent t-test is used to test the null hypothesis, with assumed unequal variance.

Mean difference: -41 (QR—EAN-13)
Standard deviation: 30.24483
T: -4.067
Degrees of freedom: 8
Significance: 0.004 (two-tailed)

Fig. 2: T-test result.

As indicated in Figure 2, t-test results in a value of -4.067, which, with 8 degrees of freedom produces the significance established by the t-test is evaluated at 0.004, which is lower than the established significance threshold of 0.05. Therefore, the null hypothesis is rejected and the results for QR code and EAN-13 mean minimum recognized sizes are significantly different. Since the mean difference between QR code and EAN-13 sets is equal to -41, it can be reasoned that QR codes can be recognized at lower sizes than EAN-13 barcodes. Thus, we reckon the original hypothesis to be correct.

Probability of correct recognition

In order to confirm our hypothesis that the QR codes are easier to recognize than EAN-13 if our entire range is considered, we compare the ratios of recognized codes to all attempts for each type of code. The necessary data was presented at the bottom of Table 5 where the aggregates were presented per image size and code type. The data were further aggregated in Table 4 where it is further folded for entire ranges of codes.

	QR Code	EAN-13	
	80-350px	80-350px	350-600px
Total correct	47	13	31
Total filed	38	70	85
Total focus	3	5	5
Hit probability	0.534	0.148	0.256

Table 4: An aggregation of results from Table 5.

The number of correct scans of a QR codes with a size between 13mm and 58mm is 47, whereas there are unrecognized 38 images and 3 failed attempts at focusing. Therefore, the probability of any of the tested QR codes being correctly recognized is in excess of 53%. Similarly, the number of correct scans of an EAN-13 code in the same size range is is 13, with 70 unrecognized images and 5 failed attempts at focusing. Therefore, the probability of any tested EAN-13 barcode (within the aforementioned images) being correctly recognized, is below 15%. In other words, if an attempt is made to recognize any of the QR codes in our experiment using a random one of the available devices, the chance of it being scanned correctly is around 53%, whereas if the code is a random EAN-13 this probability drops to around 15%.

If we were to include the increased sizes of codes in the ratios for EAN-13 code and take into account results from the range of 13mm to 108mm, we would establish that the probability of correctly recognizing an EAN-13 barcode increases only to 25.6% with the number of correct recognitions of 31, with 85 unrecognized and 5 failing to photograph. We do not have results for QR codes from the same range, but is seems safe to assume that with increased size of images the hit ratio would at worst stay at the same level.

These ratios strongly suggest that QR codes are generally easier to recognize than EAN-13 barcodes.

4 Conclusions

The analysis of the results of the experiment strives to prove that two-dimensional codes support a better quality of recognition than one-directional barcodes, especially for wide variety of mobile devices, often with low-grade on-board camera equipment.

In particular, two-dimensional codes of smaller sizes than one-dimensional codes are recognizable by our software. It should be especially noted that the sizes required by EAN-13 codes are much larger than barcodes normally found on products. On the other hand, QR codes can be read at sizes averaging at about 30mm, which is well within range of codes typically seen on products. In addition, the chances of correctly scanning QR codes in general is preferable to the probability of scanning EAN-13 barcodes.

Greater quality of recognition can be attributed to several factors, including more and better error checking mechanisms described in more detail in the Introduction. Although two-dimensional codes also provide mechanisms that minimize the effects of surface irregularities or perspective appearing in the photograph, and a number of algorithms to dampen these issues were developed for one-dimensional codes, resilience to these problems was not tested here.

It also should be noted that one-dimensional codes can carry less information than two-dimensional ones: EAN-13 are able of encoding 12 digits, and QR codes can carry up to over 7000 digits. In conjunction with the higher probability of recognition and smaller acceptable sizes of codes, two-dimensional codes, and QR codes in particular, as well as all the aforementioned advantages indicate that QR codes are the superior technology.

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Device	Image (size in pixels)																		
	EAN-13											QR Code							
	80	120	160	230	250	280	320	350	400	500	600	80	120	160	230	250	280	320	350
Apple iPhone 3G											✓			✓		✓		✓	
HTC T-Mobile G1	⊙	⊙	⊙	⊙	⊙							⊙	⊙	✓		⊙		✓	✓
Nokia 6233										✓	✓				✓	✓		✓	✓
Sony Ericsson G502									✓	✓	✓				✓	✓	✓	✓	✓
Sony Ericsson K310i						✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Sony Ericsson K510i											✓				✓		✓	✓	✓
Sony Ericsson K600i											✓				✓		✓	✓	
Sony Ericsson K750i								✓	✓	✓	✓		✓	✓	✓	✓	✓		
Sony Ericsson K850i																	✓		
Sony Ericsson T280i			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sony Ericsson W610i			✓	✓	✓						✓				✓	✓		✓	✓
Correct	0	0	2	2	2	2	2	3	4	5	9	1	3	5	8	7	7	9	7
Failed	10	10	8	8	8	9	9	8	7	6	2	9	7	6	3	3	4	2	4
Could not focus	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0
Hit ratio	0.000	0.000	0.182	0.182	0.182	0.182	0.182	0.273	0.364	0.455	0.818	0.091	0.273	0.455	0.727	0.636	0.636	0.818	0.636

Table 5: Code scanning results: ✓—correct recognition, empty—recognition failed, ⊙—camera could not focus.