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Decoding Different Patterns in Various Grey Tones Incorporated in the QR Code

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Abstract:

This paper explores the dependence of reliable decoding of grey toned QR codes on the technical characteristics of smartphone cameras marketed in the period between 2008 and 2012. The research consisted of taking a total of 12,150 QR code pictures with different grey tones, graphic patterns and error correction codes. This research answers the question whether today's smartphones can decode such designed QR codes. The data and instructions on the quantity and size of a certain grey tone incorporated in the QR code that are sufficient to decode the researched symbology have also been given. Graphic designers can use the results of this research to make QR codes that do not drastically reduce reliability.

Keywords:

QR Code, Greyscale, Designed QR codes, Mobile devices,
Reliable QR Code Decoding

1. Introduction

The intensity channel contrast between data and background modules is the most important aspect in the process of reliable bar code decoding. In practice, when big automated store chains depend on the precision and reliability of bar codes, bar code verification is often used in order to avoid bar codes of low quality. The tool which enables that is machine vision verification which identifies poor bar codes before they can do damage to a certain enterprise (financial expense, significant loss of time, productivity decrease, error increase). In order to avoid mistakes, bar code verification is performed before putting a bar code in the system. Bar code verification ensures compliance with the issued bar code quality standards such as ISO 15415 and ISO 15416. That means that it is necessary to comply with certain parameters such as symbol contrast, minimal reflection, unused error correction algorithms, quiet zone size, uneven grid, uneven axis etc. in order to correctly scan 1D and 2D bar codes (Microscan Systems, 2013). In addition to the standard black and white bar codes, there are 2D colour bar codes that can be scanned by camera phones (Microsoft Tag, Colour Code). The use of a multitude of colours causes errors that may adversely affect the readability of bar codes (Tan et al. 2010), given that the contrast between data and background modules is reduced. Research conducted by Tan, Keng T., Ong, Siong , K., Chai in 2010 has shown that even under controlled laboratory conditions (perfect 2D bar code symbol and good illumination) there are significant errors in the scanned bar code image and they are of such nature that colours substantially lose illumination (Tan et al. 2010). The experiment that consisted of capturing images of 2D bar codes in JPEG format with a camera phone has shown that the component of illumination is reduced by 40% on average (Tan et al. 2010). The conclusion is that camera phones produce darker images of 2D colour bar codes (present in all of the randomly selected patterns) (Tan et al. 2010).

The invention of infrared design and the protection of bar codes from abuse have made a contribution towards solving the problem of reading colour bar codes by incorporating different graphic forms in the visible spectrum, while the real bar code is placed underneath those layers of colour and is visible under infrared light. However, special knowledge which is not available to everyone is required for the implementation of such a procedure (Žiljak et al. 2010). Nonetheless, camera phones can still scan standard bar codes with dark lines and bright interstices in the IR spectrum. Research done by Vans, M., Simske S. and Loucks, B. in the field of document security shows that it is possible to scan information coded in colour with the help of special bar code readers. They state that colour saturation can affect the readability with standard bar code readers (Vans et al. 2013).

2. Problem statement

Given the need to attract the attention of consumers, bar codes (as part of the product) are also designed. This results in bar code designers often using colour (in addition to black and white), the application of which to bar codes can cause problems in reading and decoding the data embedded in them (Kavčić et al. 2010). Due to the unreliability of coloured bar codes, most designers still keep to the limitations placed by Pira International (Smithers Pira) in 2002, which include the use of black and white and any avoidance of intervention on the graphical level of bar codes (Williams, 2004). As this limitation was placed in 2002 and due to the above-mentioned need, this paper examines whether these same limitations apply to technologically advanced camera phones.

3. Hypothesis

MAIN HYPOTHESIS

a) The number of grey tones incorporated in a QR code does not affect the reduction of its reliability.

SUB-HYPOTHESIS

b) If a QR code incorporated with algorithms for correcting errors can be corrected, that means the grey tones do not affect its readability.

4. Research aim

Since the contrast between data modules and background modules is the most important aspect in the process of reliable bar code decoding both on paper and screen, combinations of grey tones incorporated in the QR code be examined, which gives the same results as if combinations of colours of the same tonal values were examined (*Fig. 1*).

Figure 1. Color data modules in the QR code and their values in greyscale.

This research was conducted to examine if it was possible to maintain the same level of readability, i.e. reliability of QR codes if, in addition to black and white, a combination of grey tones was incorporated in the graphic symbol as well. This would answer the question of whether mobile devices marketed in the period between 2008 and 2012 could be used to decode QR codes containing additional colours intended to display visually richer content.

5. Research

The research was conducted in two phases:

- Preliminary research
- Main research

5.1. PRELIMINARY RESEARCH: MINIMUM PIXEL SIZE

VARIABLES

The research was conducted to determine the minimum size of modules at which QR codes can still be read by most cell phones. It was conducted on 11 July 2012 on the following phones: iPhone 3G , iPhone 3GS, Sony Ericsson Xperia Arc, Nokia N97, Sony Ericsson Xperia X10 mini, Sony Ericsson E10i and Samsung GT 15500. The research analyzed a total of six QR codes in different sizes, generated on the following website: http://keremerkan.net/qr-code-and-2d-code-generator/. The same message was incorporated in all the QR codes and they all had the same level of error correction - the Q level (25 % of errors can be corrected). The results of this research can be seen in the table (*Table 1*). The research was conducted on seven different mobile devices at two different temperatures of light (5000 K and 7500 K) and at a distance of 6 cm to 50 cm between the camera phones and the QR code image on paper. Each cell phone was used 3 times to try to decode each QR code.

CONCLUSION OF THE PRELIMINARY RESEARCH

All of the above-mentioned phones read QR codes from smaller and greater distances reliably if they are 20 x 20 mm in size (*Fig. 2*).

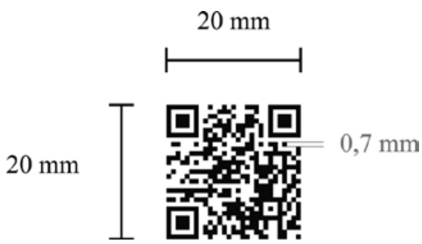

Figure 2. The minimum size of the QR code (20 x 20 mm) with the minimum cell size (0.7 mm)

Table 1. Minimum and maximum distances (in cm) from which a QR code (in different sizes - in mm) can be read. Measurements were carried out on 7 different mobile devices at two different temperatures of light (5000 K and 7500 K)

QR code size	iPhone 3G		iPhone 3GS		Sony Ericsson Xperia Arc		Nokia N97	
	5000 K	7500 K	5000 K	7500 K	5000 K	7500 K	5000 K	7500 K
30 mm	6-40	6-41	6-48	6-48	7-50	8-50	11-50	11-50
25 mm	6-30	6-35	5-41	6-41	6-50	7-50	11-50	11-50
20 mm	7-24	6-25	5-33	5-31	6-50	6-50	10-45	9-46
15 mm	/	/	5-32	4-24	7-40	7-40	7-32	7-32
10 mm	/	/	5-11	6-15	10-26	10-26	/	/
5 mm	/	/	/	/	/	/	/	/

QR code size	Sony Ericsson Xperia X10 mini		Sony Ericsson Xperia E10i		Samsung GT 15500	
	5000 K	7500 K	5000 K	7500 K	5000 K	7500 K
30 mm	6-50	6-50	6-50	6-50	5-29	6-29
25 mm	6-42	6-42	6-42	6-42	5-24	5-24
20 mm	6-34	6-34	6-34	6-34	4-20	4-19
15 mm	6-26	6-26	6-26	6-26	5-11	5-12
10 mm	6-11	6-15	6-11	6-15	/	/
5 mm	/	/	/	/	/	/

That means that the minimum size of the QR code module for correct reading is 0.7 x 0.7 mm. Only iPhone 3G failed to read the QR code 15 x 15 mm in size, while all other cell phones managed to do it without much difficulty. Excluding iPhone 3G, the smallest QR code module size can be 0.52 x 0.52 mm. The temperature of light (5000 K and 7500 K) has no effect on the readability of QR codes in different sizes, i.e. the same cell phone was able to read the QR code of the same size at different temperatures.

5.2. MAIN RESEARCH: QR CODES WITH GREYSCALE

RESEARCH VARIABLES

Two variables were employed in the research.

1. The number of combinations of grey tones in the QR code

2. The area that is covered by a certain grey tone in the QR code

It is important to emphasize that all the grey tones are a substitute for data modules, while the background is white.

These two variables had three different levels of Reed-Solomon (RS) algorithms, and the QR codes were generated on the following website: http://keremerkan.net/qr-code-and-2d-code-generator/. Each generated code had a built-in message with a low (L level), medium (M level) and high level (H level) of RS algorithms. The reason for the exclusion of other variables such as different printing techniques, different types of media (paper, screen, metal), different types of scans etc. is that first it was explored whether it was even possible to incorporate greyscale without compromising the reliability of QR codes. If this research showed that the readability of certain combinations of grey tones was identical as with black and white QR codes, a detailed analysis would be conducted by using and including the above-mentioned variables.

The research on greyscale was conducted on smartphones with higher quality cameras than that of an iPhone 3G (2 MPx camera) that was marketed in 2008, and these are iPhone 3Gs (3 MPx camera) marketed in 2009, Sony Ericsson Xperia Arc (8.1 MPx camera) marketed in 2011 and VIP racer III (5 MPx camera) marketed in 2012. It was also decided that greyscale research be conducted on a sample 20 x 20 mm in size, given that this size proved reliable for cell phones in the previous research. The application that was selected for scanning QR codes with greyscale was 3GVision's i-nigma (http://www.i-nigma.com/i-nigmahp.html) because of its reliability and good user experience. With this mobile application it wasn't possible to change the settings of the mobile camera, which is evident form the screenshot (*see Fig. 3*).

Therefore, the following default settings were used:

Table 2. Characteristics of all smartphones in the main research.

iPhone 3GS	Sony Ericsson Xperia Arc	VIP racer III
2048×1536 pixels	3264 x 2448 pixels	2592x1944 pixels
OV3650 color sensor	Exmor R backlit CMOS sensor	/
f/2.8	f/2.4	/
no flash	no flash	no flash

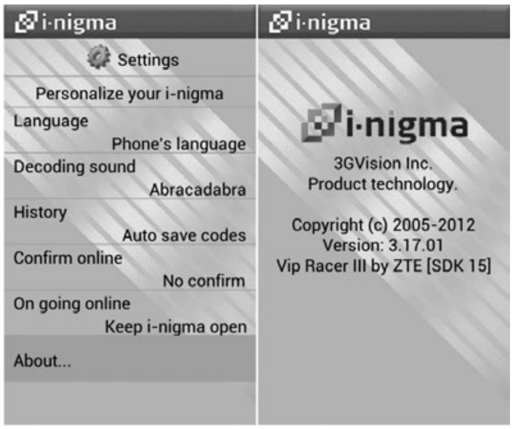

Figure 3. Settings and version of iNigma application for Sony Ericsson Experia Arc.

METHODOLGY

Measurements of grey tones examined in this research were carried out at two different temperatures of light (5000 K and 7500 K) using smartphones, from a constant distance (20 cm) for both temperatures.

For the cell phone camera, i.e. the reader, each colour represents a single tone which is compared with the background. If the tone is sufficiently distinctive to be displayed as dark in relation to the background, the application, i.e. the bar code reader, will identify it as a black module, and if it is light and similar to the background, the cell phone camera will identify it as a white module (ISO/IEC, 2005). It is precisely this knowledge that is important when designing forms (simple geometric, typographic or complex) so that modules, which can be used to add volume, focus, clarity, reality, intelligibility, readability and generally richer visual content and character to a particular logo, sign, image, symbol or letters displayed on the graphic part of the QR code, can be interpreted correctly.

QR codes with combinations of grey tones were printed on 220 g/m2 woodless cardboard (MULTI PURPOSE OFFICE PAPER - produced by Radeče Paper Mill, Slovenia) CMYK (inkjet technology, Canon Pixma PRO9000), where the values C, M and Y remained the same throughout the research (C = 0, M = 0, Y = 0) and only the K value changed. Combinations of grey tones that were examined are:

Table 3. Grey tones that were used in the research sorted into 4 groups.

	A	B	C	D
1.	K=50	K=33	K=25	K=20
2.	K=100	K=66	K=50	K=40
3.		K=100	K=75	K=60
4.			K=100	K=80
5.				K=100

Grey tones within a single group were permuted, which means that different parts of a graphic pattern took on other tonal values. The numbers in front of the K values were later used to describe the sequence of grey tone combinations. In the analysis, those sequences of tones are shown in the tables, a segment of which can be seen in *Table 4*. In order for the variable of area to change, it was necessary to create several graphic patterns for analysis. Forms that were "underneath" the QR codes had different areas of grey tones that varied during the research, depending on the number of incorporated tones (*Fig. 4*).

A total of 9 different graphic patterns was made.

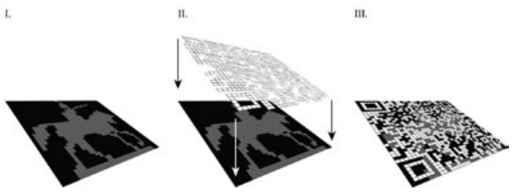

Figure 4. Setting the image "underneath" the QR code.

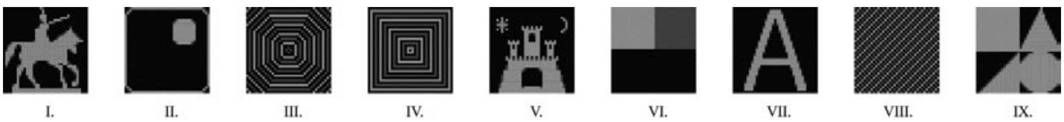

Figure 5. Graphic patterns for the research on the variable of area of greyscale. Order of graphic patterns: I, II, III, IV, V, VI, VII, VIII, IX.

These nine graphic patterns were chosen on the basis of 3 different categories: abstract graphic patterns (patterns II, III, IV, VI, VIII, IX), typographic patterns (pattern VII) and complex graphic patterns (patterns I, V). Within every category, graphic patterns were chosen at random because every designer of a bar code makes their own solution depending on their desires and needs. In order to verify the correctness of their own solution, the bar code designer does the following: First of all, it is necessary to set the design in greyscale mode. Depending on the solution, the designer sets it in one of the three previously mentioned categories. Then their solution is compared to the graphic pattern closest to its own within the chosen category. By looking at the table of percentages of grey tones (Table 4) and the conclusion of this article, the designer can know in advance whether a smartphone that entered the market between 2008 and 2012 would be able to decode their solution implemented in the background of a bar code as it is explained in this article (*Fig. 4*). Areas of greyscale were obtained as follows. First, it was necessary to know the total number of modules in the graphic pattern square. Given that all of the squares were of the same size, it was enough to count the modules on one side of the square. Consequently, the number 1396 (27^2) was obtained. Then the modules for each grey tone were added together by determining the group of modules of a certain number, e.g. the group with 20 modules, which is called Group 1 (*see Fig. 6, II*). Group 1 was later (*see Fig. 6, II*) added to the area whose number of modules was supposed to be calculated.

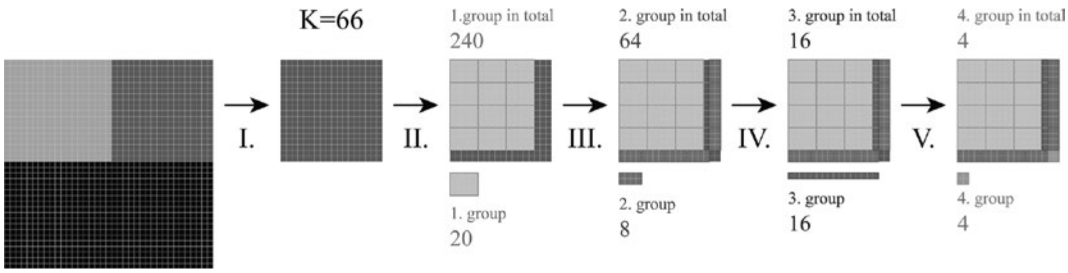

Figure 6. Example of calculating the total number of modules in the area of the grey tone K = 66 in the graphic pattern VI.

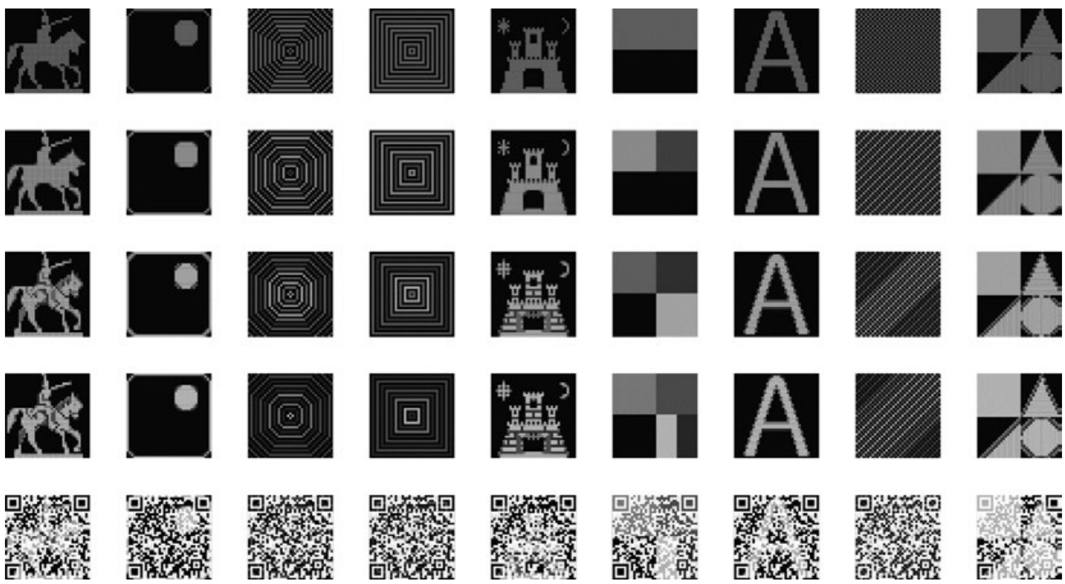

Figure 7. Examples of areas of grey tones in the graphic patterns

The total number of modules that the grey tone K = 66 covered (324 modules) was obtained by adding up these modules (240 + 64 + 16 + 4). That is how it was concluded that the grey tone K = 66 in the graphic pattern VI covered 23.21% of the area ((324 / 1396) * 100 = 23.21%). The same procedure was repeated for each form of grey tones that made up a graphic pattern. Some combinations of grey tones can be seen in *Fig. 7*, and in *Table 4* percentages of areas of grey tones in the graphic patterns are visible for each combination.

Based on this information, the number of tones and the area that can be allocated to each grey tone in a QR code (without compromising the reliability of the bar code) was determined.

ANALYSIS OF THE FIRST VARIABLE - THE NUMBER OF COMBINATIONS OF GREY TONES IN THE QR CODE

To analyze the data, a descriptive method of statistical analysis was used in order to see how much the reliability of decoding QR codes was reduced on average.

An image of each QR code was captured 9 times at the same temperature of light. The first three times iPhone3GS was used, the following three times Vip Racer III and the last three times Sony Ericsson Xperia Arc. Decoded images were marked with a plus sign, and those that could not be decoded with a minus.

Each graphic pattern (9 in total) was set underneath 3 different QR codes, each of which had a different level of RS algorithms. The research analyzed a total of 25 different combinations of grey tones as previously discussed in this paper. From these data it is possible to see that the total number of images captured at one temperature of light equals 6075 (9 * 9 * 3 * 25 = 6075). This means that a total of 12150 pictures were taken during this research (6075 pictures at 5000 K and 6075 at 7500 K). Given the amount of data, for the purposes of this paper the results of individual combinations were extracted (*Table 5 and Table 6*).

The results for 5000 K are represented in white in the tables, and those for 7500 K in grey.

Table 4. Percentages of areas of grey tones in the graphic patterns for some combinations of grey tones.

combinations of grey tones	graphic patterns								
12	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
1. K=50	34,33%	16,8%	40,91%	47,33%	33,45%	48,65%	23,3%	50,04%	72,53%
2. K=100	65,67%	83,2%	59,09%	52,67%	66,54%	51,35%	76,7%	49,96%	27,46%
123	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
1. K=33	32,72%	16,8%	19,28%	26,30%	32,65%	24,98%	20,53%	25,05%	68,81%
2. K=66	4,46%	1,46%	21,62%	21,04%	2,99%	23,67%	2,78%	24,98%	3,8%
3. K=100	62,82%	81,74%	59,09%	81,74%	64,35%	51,35%	76,7%	49,96%	27,39%
4231	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
4. K=100	62,31%	80,86%	59,09%	52,67%	61,58%	26,37%	72,83%	49,96%	27,32%
2. K=50	9,42%	2,34%	19,28%	26,30%	7,38%	24,98%	3,65%	25,05%	4,02%
3. K=75	3,72%	0,88%	14,9%	15,19%	8,40%	23,67%	4,09%	11,39%	4,89%
1. K=25	24,54%	15,92%	6,72%	5,84%	22,64%	24,98%	19,43%	13,59%	63,77%
52341	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
5. K=100	62,31%	80,86%	59,09%	52,67%	62,09%	26,37%	72,83%	49,96%	27,39%
2. K=40	4,82%	0,29%	6,43%	4,09%	4,02%	24,98%	3,65%	6,14%	4,02%
3. K=60	4,6%	0,58%	14,9%	15,19%	3,94%	23,67%	2,99%	25,05%	4,89%
4. K=80	3,43%	2,34%	26,59%	26,3%	7,23%	12,49%	1,1%	5,26%	4,38%
1. K=20	24,84%	15,92%	0,29%	1,75%	22,72%	12,49%	19,43%	13,59%	59,31%

Table 5. The combinations of grey tones that have the highest reliability

												IN TOTAL		PERCENTAGE	
Grey tones	RS	1.	2.	3.	4.	5.	6.	7.	8.	9.	RS	individu.	all	individu.	all
12	**Low**	(6/9)	(9/9)	(2/9)	(3/9)	(6/9)	(9/9)	(9/9)	(0/9)	(6/9)	**Low**	(50/81)	(182/243)	61,72%	74,90%
	Medium	(9/9)	(9/9)	(3/9)	(3/9)	(9/9)	(9/9)	(9/9)	(2/9)	(9/9)	**Medium**	(62/81)		76,54%	
	High	(9/9)	(9/9)	(7/9)	(6/9)	(9/9)	(9/9)	(9/9)	(3/9)	(9/9)	**High**	(70/81)		86,42%	
12	**Low**	(3/9)	(6/9)	(2 /9)	(3/9)	(3/9)	(9/9)	(9/9)	(0/9)	(3/9)	**Low**	(38/81)	**(161/243)**	46,91%	**66,25%**
	Medium	(9/9)	(9/9)	(1/9)	(3/9)	(9/9)	(9/9)	(9/9)	(1/9)	(9/9)	**Medium**	(59/81)		72,84%	
	High	(9/9)	(9/9)	(6/9)	(3/9)	(9/9)	(9/9)	(9/9)	(1/9)	(9/9)	**High**	(64/81)		79,01%	
21	Low	(3/9)	(9/9)	(3/9)	(0/9)	(7/9)	(9/9)	(9/9)	(1/9)	(9/9)	Low	(50/81)	(187/243)	61,72%	76,95%
	Medium	(9/9)	(9/9)	(6/9)	(3/9)	(9/9)	(9/9)	(9/9)	(2/9)	(9/9)	Medium	(65/81)		80,25%	
	High	(9/9)	(9/9)	(9/9)	(6/9)	(9/9)	(9/9)	(9/9)	(3/9)	(9/9)	High	(72/81)		88,89%	
21	Low	(3/9)	(9/9)	(3/9)	(0/9)	(3/9)	(9/9)	(6/9)	(1/9)	(6/9)	Low	(34/81)	**(158/243)**	41,97%	**65,02%**
	Medium	(9/9)	(9/9)	(3/9)	(3/9)	(7/9)	(9/9)	(9/9)	(1/9)	(9/9)	Medium	(59/81)		72,84%	
	High	(9/9)	(9/9)	(6/9)	(3/9)	(9/9)	(9/9)	(9/9)	(2/9)	(9/9)	High	(65/81)		80,25%	

Table 6. The combination of grey tones that has the lowest reliability

												IN TOTAL		PERCENTAGE	
Grey tones	RS	1.	2.	3.	4.	5.	6.	7.	8.	9.	RS	individu.	all	individu.	all
21345	**Low**	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	Low	(0/81)	(1/243)	0,00%	0,41%
	Medium	(0/9)	(1 /9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	Medium	(1/81)		1,23%	
	High	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	High	(0/81)		0,00%	
21345	**Low**	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	Low	(0/81)	**(0/243)**	0,00%	**0,00%**
	Medium	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	Medium	(0/81)		0,00%	
	High	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	High	(0/81)		0,00%	

If the temperatures are not observed individually, the research (*Table 5*) shows that the combination of grey tones with values K = 50 and K = 100 has the highest reliability with all three levels of RS algorithms, and on the individual level of the temperature of light the highest reliability was maintained with the combination K = 50 and K = 100 (21) for 5000 K and the combination K = 50 and K = 100 (12) for 7500 K.

The combination with 5 different grey tones (K = 20, K = 40, K = 60, K = 80 and K = 100 -21345) has the lowest reliability with all three levels of RS algorithms (*Table 6*), and on the individual level of the temperatures of light the lowest reliability was maintained with the same combination (21345) for both 5000 K and 7500 K. By analyzing the individual temperatures of light the following results are obtained.

5000 K - Based on the research on scanning QR codes with greyscale at the temperature of 5000 K, their reliability dropped by a total of -71.61%. This means that 1774 of 6075 images were successfully decoded (*see Table 7*).

7500K – At the temperature of light of 7500 K the reliability of QR code decoding dropped by -72.33%. This means that 1681 of 6075 images of QR codes were successfully decoded (*see Table 7*).

What can be inferred from *Table 7* is that QR codes that were incorporated with a **high** level of Reed-Solomon algorithms have the smallest loss of reliability, and those that were incorporated with a **low** level of RS algorithms have the greatest loss of reliability. If the results from Table 6 are added up (5000K - 1774/6075 and 7500K - 1682/6075), it can be noted that in relation to the temperature of light of 7500 K, 93 QR codes more (0.72%) were scanned at the temperature of light of 5000 K.

Table 7. Reliability of all grey tones for all 9 graphic patterns.

	RS	IN TOTAL	PERCENTAGE
All tones	**Low**	(282/2025)	13,93%
All tones	**Medium**	(582/2025)	28,74%
All tones	**High**	(910/2025)	44,94%
All tones	**Low**	(250/2025)	12,34%
All tones	**Medium**	(552/2025)	27,26%
All tones	**High**	(880/2025)	43,46%

ANALYSIS OF THE SECOND VARIABLE - THE AREA THAT IS COVERED BY GREY TONES IN THE QR CODE

The following table shows the sums of successfully decoded images whose values are left from the slashes, while the total number of attempts at decoding the images is on the right. The sums were obtained by adding up the decoded images in each group that represents certain combinations of grey tones in a graphic pattern, regardless of the temperature of light (*Table 8*).

The percentages in *Table 8* are taken from the research results, a segment of which can be seen in *Table 4*.

Table 8. Overview of the sums of successfully decoded images by the total combinations of grey tones (groups A, B, C, D) for all 9 of the graphic patterns.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX. (Graphic patterns)	Grey tone
AREAS OF GRAPHIC PATTERNS IN QR CODE								A	
IN TOTAL: 12 + 21									
(87/108)	(105/108)	(51/108)	(36/108)	(89/108)	(108/108)	(105/108)	(17/108)	(96/108)	
					48,65%		50,04%		K=50
					51,35%		49,96%		K=100
AREAS OF GRAPHIC PATTERNS IN QR CODE								B	
IN TOTAL: 123+132+213+231+312+321									
(63/324)	(157/324)	(0/324)	(0/324)	(140/324)	(304/324)	(153/324)	(0/324)	(72/324)	
		19,28%	26,30%		24,98%		25,05%		K=33
		21,62%	21,04%		23,67%		24,98%		K=66
		59,09%	81,74%		51,35%		49,96%		K=100
AREAS OF GRAPHIC PATTERNS IN QR CODE								C	
IN TOTAL: 2134+2341+2413+3124+3412+4123+4231+4312									
(115/432)	(278/432)	(0/432)	(0/432)	(93/432)	(218/432)	(201/432)	(0/432)	(151/432)	
	15,92%	6,72%	5,84%				13,59%		K=25
	2,34%	19,28%	26,30%				25,05%		K=50
	0,88%	14,90%	15,19%				11,39%		K=75
	80,86%	59,09%	52,67%				49,96%		K=100
AREAS OF GRAPHIC PATTERNS IN QR CODE								D	
IN TOTAL: 21345+25134+31452+32145+42351+43512+51234+53412+54123									
(87/486)	(247/486)	(0/486)	(0/486)	(98/486)	(112/486)	(187/486)	(0/486)	(76/486)	
	15,92%	0,29%	1,75%				13,59%		K=20
	0,29%	6,43%	4,09%				6,14%		K=40
	0,58%	14,90%	15,19%				25,05%		K=60
	2,34%	26,59%	26,30%				5,26%		K=80
	80,86%	59,09%	52,67%				49,96%		K=100

6. Discussion

The results have shown that the incorporation of grey tone combinations (at two different temperatures) causes a loss of reliability, so the hypothesis put forward in this research is rejected. Therefore, it is necessary to retain a single tone for data modules, preferably with the strongest contrast, black for data and white for the background, in order to avoid the loss of reliability. Although it has been shown that with QR codes containing a high level of Reed-Solomon algorithms there is less loss of reliability than with those containing a low level of RS algorithms (*Table 7*), that is not enough to maintain the same level of reliability as with standard bar codes, i.e. those containing only one tone to display data. It has also been concluded that the QR code that has a combination of only two grey tones to display data modules has the smallest loss of reliability, while the least reliable QR code was the one containing a combination of 5 grey tones to display data modules. This means that it is not possible to incorporate the examined combinations of tones to display images with richer visual content while maintaining the same reliability as with standard bar codes. In this sense, it is necessary to conduct further research to discover which other combinations of two tones for data modules can be incorporated to achieve the highest possible level of reliability. The results of this research also show that the forms that consist of alternating grey tones of different values - graphic patterns III, IV and VIII - exhibit very weak results in terms of being read by cell phone cameras. The graphic patterns II and VI have exhibited the best results (*see Table 8*).

7. Conclusion

The technology of optical bar code scanning with camera phones in the period from 2008 to 2012 has still not allowed the incorporation of a few grey tones of different values, especially in a greater number of combinations, because it drastically reduces the reliability of QR codes. It can therefore be concluded that spaces with dark modules with great variation in the tones should be avoided (graphic patterns III, IV and VIII). If other tones that create a complex form (like other examples in the research) are used, they need to be used in such a ratio that the tone with the value K = 100 occupies 80% of the area, and the remaining 20% is occupied by grey tones in order to maintain high reliability. If an abstract form (where the grey tones are placed in one part of the form as with the graphic pattern VI) is used, it is necessary to use such a ratio in which the tone of the value K = 100 occupies 50% of the area, and the remaining 50% is occupied by grey tones in order to maintain high reliability

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