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Fast Statistical Image Binarization of Colour Images for the Recognition of the QR Codes

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***Abstract*—The article concerns the fast image binarization based on the application of the statistical Monte Carlo method applied for the recognition of the QR codes from colour images, especially captured by mobile devices' cameras. Due to limited processing possibilities of some mobile devices as well as relatively low quality of some optical systems in built-in cameras, fast binarization methods are very useful for rapid recognition of the 2-D binary codes which can be found on the packages of various products and even on the street billboards. Captured images of such QR codes usually contain some background objects, may be blurred or may contain some other distortions which can hamper or make it impossible to recognize the code even considering the presence of redundant data included using Reed-Solomon's code. These problems may also occur in differing lighting conditions where the impact of binarization method and its results may be critical for further processing. The experimental results presented in the paper obtained for various colour spaces confirm the usefulness of the fast Monte Carlo based image binarization for the fast recognition of the QR codes, especially in presence of distortions and varying lighting conditions. Additionally, high performance of the Monte Carlo method allows checking different variants of binarization in order to choose the most appropriate one.**

***Index Terms*—Image analysis, image recognition, Monte Carlo method.**

I. INTRODUCTION

Recognition of various two-dimensional binary codes, such as well-known Quick Response (QR) codes, is one of the fundamental functionalities of modern mobile devices, such as smartphones or tablets. One of the main assumptions of such codes is the ability of fast decoding the text information stored in the binary form in the image representing the printed or displayed code. This technology, originating from the automotive industry, is currently used for many various purposes, such as coding of the WWW addresses for mobile devices e.g. for commercial purposes (on billboards, posters, leaflets etc.), coding of data e.g. in electronic tickets or invoices, marking of products in warehouses etc.

Assuming the good lighting conditions and generally good quality of the input image (high contrast, sharpness, no deformations etc.), such technology is reliable and useful, especially considering the presence of redundant information which can be used for error correction purposes e.g. using Reed-Solomon's code. Therefore the possibility of wrong result obtained from the decoder is extremely low (in general is it assumed that the obtained text is correct or none) and the only problem may be related to the code localization [1].

Nevertheless, the nature of the image data in the QR code images is binary whereas the cameras work in colour mode so the captured images have to be converted into the binary form prior recognition of the code. For the images containing some distortions, e.g. geometrical or related to colour and/or contrast, containing dirty fragments, especially observed in non-uniform lighting conditions the binarization results may be ambiguous and can influence the result of recognition. Since the binary codes are almost everywhere, even using relatively good camera optical systems used in the latest mobile devices, there may be some problems with such QR codes, which can be often solved by slight modifications of the software related to appropriate preprocessing of the acquired image.

However, such operations should be fast in order to use possibly small amount of available resources, so the application of the Monte Carlo method allowing to use only the part of image data for analysis, is worth investigating. An additional advantage of such approach is the fact that there is no risk of improper recognition of text data even if some additional errors would be accidentally introduced e.g. due to the use of too small number of samples.

In this paper some experimental results have been presented which are related to the application of the fast statistical image binarization of colour images based on the use of various colour spaces. Obtained results confirm the possibility of increasing the ratio of properly recognized QR codes in comparison to recognition of the acquired image without any preprocessing operations.

All the experiments have been conducted using Matlab environment and open source cross-platform ZBar binary code reader being available at: http://zbar.sourceforge.net/.

II. THE IDEA OF THE PROPOSED APPROACH

Experiments conducted using various images containing the QR codes have led to the conclusion that the recognition of them may be troublesome when the original images are subjected to recognition directly. In many situations much

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better recognition accuracy may be obtained after a change of the colour model or conversion to greyscale and further binarization. Nevertheless, obtained results depend on the method of binarization as well as the colour model used for colour image representation. One of the possible solutions which may be applied for increase of the possibility of proper recognition of the QR code may be conversion of the image from RGB colour model into some other popular colour spaces such as CIE XYZ, CIE LAB, HSV, YIQ or YCbCr. Nevertheless, for some of the colour models, only the luminance/brightness related channels should be further considered, e.g. L from CIE LAB, V from HSV or Y from YIQ, as the chrominance channels usually do not contain the data useful for further binarization and recognition. The QR code recognition may be then applied independently for each such obtained image and it can be assumed that a single proper result obtained for any of those colour models is enough.

Since the colour conversions and binarizarion increase the computational cost, it can be reduced by choosing the linear conversions from the RGB space as the first attempts leaving CIE LAB colour model as the last one since this conversion requires more computations. Nevertheless, in order to reduce the complexity of the binarization part the application of the Monte Carlo method is proposed. As this method belongs to the family of fast statistical algorithms, a significant reduction of the amount of processed data can be obtained. A similar approach can also be successfully applied for preliminary video analysis and image quality estimation [2] as well as for fast binarization of document images [3], [4].

The drawing procedure is conducted on the reshaped one-dimensional vector of N pixels from the analysed block. The n independent numbers are generated by pseudo-random generator of uniform distribution with good statistical properties. For all randomly chosen pixels the total number of chosen points (k) is then calculated which is used for the fast estimation of the simplified image histogram. Estimated level of the single bin of the histogram obtained in the Monte Carlo experiment is equal to

$$\widehat{L}_{\mathrm{MC}} = \frac{k}{n} \times N, \tag{1}$$

where k denotes the number of drawn pixels for the specified luminance level in randomly chosen samples, n is the total number of draws and N is the total number of samples in the entire block.

The estimation error can be calculated as

$$\text{£}_{\alpha} = \frac{u\alpha}{\sqrt{n}} \sqrt{\frac{K}{N} \times \left(1 - \frac{K}{N}\right)}, \tag{2}$$

where K stands for the total number of samples with specified luminance level in the entire block and u_α is the value denoting two-sided critical range.

In order to increase the computational speed the random choice of pixels with difference luminance levels can be made in parallel.

In the approach proposed in this paper it is assumed that some well-known histogram based image binarization methods, such as Otsu [5] and Kapur [6] algorithms, are used. Since the binarization threshold is obtained on the basis of the analysis of the image histogram, it requires typically the counting of all pixels belonging to each luminance level in order to build the histogram (for each channel used in computations). In the proposed solution the Monte Carlo method can be applied for the estimation of the histogram significantly reducing the number of pixels used for this purpose.

The verification of the influence of the colour space on the results of binarization and QR codes recognition has been conducted using several publicly available images obtained from Internet resources containing various QR codes. The images used in experiments have been intentionally chosen as “hard to recognize” for the ZBar code reader used for the verification of results. An exemplary representative set of original images is illustrated in Fig. 1.

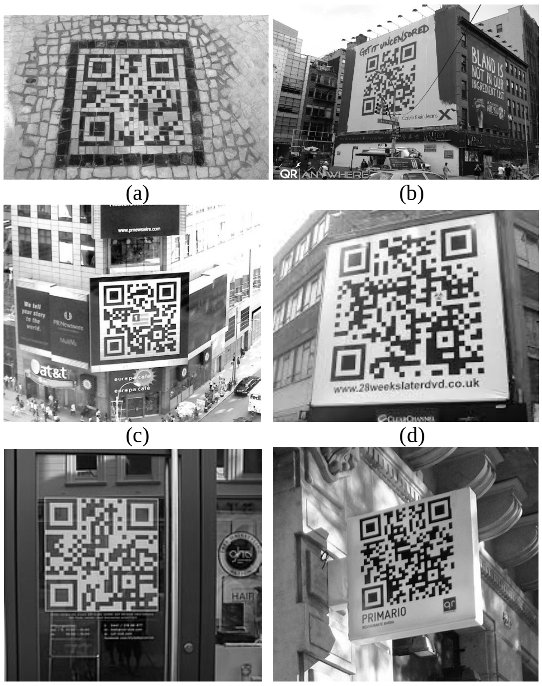


Fig. 1. Exemplary original colour images (converted to greyscale) used in the experiments.

The application of the Monte Carlo method for the fast histogram estimation for Otsu and Kapur binarization has been conducted using various numbers of randomly chosen pixels. Then the estimated histogram has been built on the basis of this limited number of drawn pixels and finally the binarization threshold has been chosen applying Otsu or Kapur algorithm using only the available data from such simplified histogram. The resolutions of the input images are different but the chosen numbers of drawn pixels are always a relatively small percentages of all pixels (from N = 20 to N = 1000 pixels have been used).

III. DISCUSSION OF EXPERIMENTAL RESULTS

The exemplary results of binarization of some images for various colour spaces illustrating their influence on the obtained results are presented in Fig. 2 for Otsu method without the application of the Monte Carlo method.

As it can be observed for some obtained images the QR code is not visible so its recognition is not possible. In some cases the chosen binarization threshold caused some distortions on the binary image resulting mainly from the non-uniform illumination which may be observed for a specified channel.

Additionally, some exemplary results of binarization for the Monte Carlo based Otsu method are shown in Fig. 3.

Fig. 2. Results of Otsu binarization for various colour spaces and channels: (a) – R (RGB); (b) – G (RGB); (c) – B (RGB) X, (d) – (CIE XYZ); (e) – V (HSV); (f) – Y (YIQ).

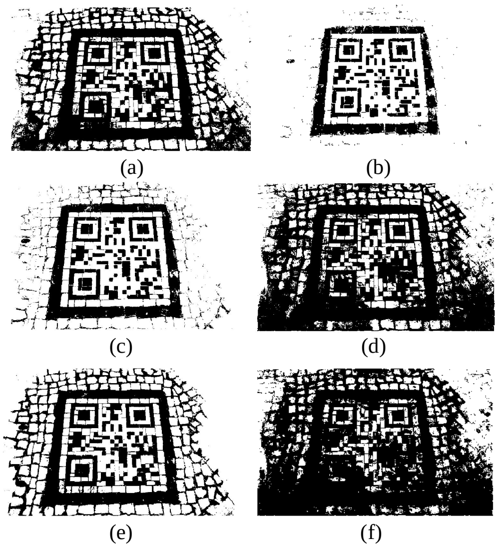


Fig. 3. Results of the Monte Carlo based Otsu binarization for different number of randomly chosen samples and various colour spaces and channels: (a) – V (HSV) – N=1000; (b) – Y (YCbCr) – N=20; (c) – Y (YIQ) – N=20; (d) – L (CIE LAB) – N=50; (e) – B (RGB) – N=100; (f) – B (RGB) – N=50.

Nevertheless, the main verification is not the result of binarization but the final effect of QR code recognition. For some binary images which seem to be easily readable for the binary code scanner, the results of the QR code recognition were unsatisfactory as shown in details in Table I–Table IV.

The obtained results prove the influence of the colour model on the recognition accuracy of the QR codes as well as confirm the usefulness of the proposed idea of changing the colour model also using the fast Monte Carlo based image binarization for this purpose.

As can be noticed, in many cases the number of randomly chosen pixels in the Monte Carlo histogram estimation can be significantly reduced without a great influence on the recognition accuracy. Nevertheless, due to the random character of the method, especially for extremely small number of samples there is no guarantee that the obtained threshold value would lead to the binary image with well visible and readable QR code. Therefore after unsuccessful recognition the drawing of samples can be repeated a few times and then the number of samples can be increased.

TABLE I. DETAILED RESULTS OF THE QR CODE RECOGNITION FOR THE TOP LEFT IMAGE FROM FIG.1.

	**R**	**G**	**B**	**X**	**Y**	**Z**	**LAB**	**YIQ**	**YCbCr**	**HSV**
256 levels	–	–	–	–	–	–	–	–	–	–
Otsu (full image)	+	+	+	+	+	–	+	+	+	+
Kapur (full image)	+	+	+	–	–	–	–	+	+	+
Otsu (N=20)	–	+	–	–	+	–	+	–	–	–
Kapur (N=20)	+	–	–	–	–	–	–	–	–	+
Otsu (N=50)	+	+	+	–	+	–	+	+	+	+
Kapur (N=50)	–	+	–	–	–	–	–	–	–	+
Otsu (N=100)	+	+	+	–	+	–	+	+	+	+
Kapur (N=100)	–	+	–	–	–	–	+	+	–	–
Otsu (N=200)	+	+	+	+	+	+	+	+	+	+
Kapur (N=200)	+	+	–	–	–	–	+	+	+	+
Otsu (N=500)	+	+	+	+	+	–	+	+	+	+
Kapur (N=500)	+	+	+	–	–	–	+	+	+	+
Otsu (N=1000)	+	+	+	+	+	–	+	+	+	+
Kapur (N=1000)	+	+	+	–	–	–	–	+	+	+

TABLE II. DETAILED RESULTS OF THE QR CODE RECOGNITION FOR THE TOP RIGHT IMAGE FROM FIG.1.

	**R**	**G**	**B**	**X**	**Y**	**Z**	**LAB**	**YIQ**	**YCbCr**	**HSV**
256 levels	–	–	+	–	–	+	–	–	–	–
Otsu (full image)	–	–	+	+	+	+	–	–	–	–
Kapur (full image)	–	–	–	+	+	+	–	–	–	–
Otsu (*N*=20)	–	+	+	–	+	–	+	+	–	–
Kapur (*N*=20)	–	–	–	–	–	–	+	–	–	–
Otsu (*N*=50)	–	–	–	+	+	+	–	+	–	–
Kapur (*N*=50)	–	–	–	–	–	–	–	–	–	–
Otsu (*N*=100)	–	+	+	–	–	+	–	–	+	–
Kapur (*N*=100)	–	–	–	–	–	–	–	–	–	–
Otsu (*N*=200)	–	–	–	–	+	–	–	–	+	–
Kapur (*N*=200)	–	–	–	–	+	+	–	–	–	–
Otsu (*N*=500)	–	–	+	+	+	+	–	–	–	–
Kapur (*N*=500)	–	–	–	+	–	+	–	–	–	–
Otsu (*N*=1000)	–	–	+	–	+	+	–	–	–	–
Kapur (*N*=1000)	–	–	–	+	+	+	–	–	–	–

The results presented in Table I are a good illustration of the necessity of binarization, as the QR code visible on the image have not been recognized properly for any of the colour models without the binarization. On the other hand, the influence of the colour model can be clearly observable analysing the results presented in Tables II and III. For most of the images in some colour models only the application of the Monte Carlo method allows the proper recognition of the QR codes. Nevertheless, the results are dependent on the number of samples so repeated draws may be necessary.

The additional proposed solution which can be applied for extremely hard images may be the division of an image into blocks in order to perform the adaptive binarization which is quite popular approach also for the binarization of degraded document images [7], [8]. The size of the block can be chosen experimentally allowing the local change of background from black to white, as black background may be much more troublesome for the QR code recognition software such as ZBar, than widely used white margins.

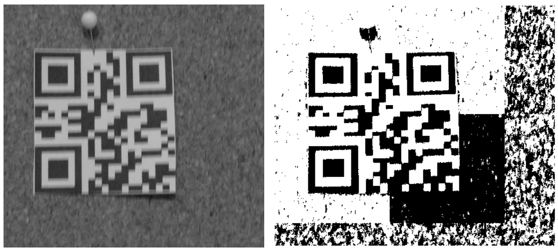
TABLE III. DETAILED RESULTS OF THE QR CODE RECOGNITION FOR THE BOTTOM LEFT IMAGE FROM FIG.1.

	**R**	**G**	**B**	**X**	**Y**	**Z**	**LAB**	**YIQ**	**YCbCr**	**HSV**
256 levels	–	+	–	–	+	+	+	+	+	–
Otsu (full image)	–	+	–	–	–	–	–	–	–	–
Kapur (full image)	–	+	–	–	–	–	+	+	+	–
Otsu (*N*=20)	–	+	–	–	–	–	–	–	–	–
Kapur (*N*=20)	–	–	–	–	–	–	–	–	–	–
Otsu (*N*=50)	–	+	+	–	–	–	–	+	–	–
Kapur (*N*=50)	–	–	–	–	–	–	–	–	–	–
Otsu (*N*=100)	–	+	–	–	–	–	–	–	–	–
Kapur (*N*=100)	–	–	–	–	–	–	–	–	–	–
Otsu (*N*=200)	–	+	–	–	–	–	–	–	–	–
Kapur (*N*=200)	–	+	–	–	–	+	–	–	–	–
Otsu (*N*=500)	–	+	+	–	–	–	–	–	–	–
Kapur (*N*=500)	–	+	–	–	+	+	–	–	–	–
Otsu (*N*=1000)	–	+	–	–	–	–	–	–	–	–
Kapur (*N*=1000)	–	+	–	–	–	+	–	+	–	–

TABLE IV. DETAILED RESULTS OF THE QR CODE RECOGNITION FOR THE IMAGE WITH CORK BACKGROUND.

	**R**	**G**	**B**	**X**	**Y**	**Z**	**LAB**	**YIQ**	**YCbCr**	**HSV**
256 levels	+	+	–	–	–	–	+	+	+	+
Otsu (full image)	+	–	–	–	–	–	–	–	–	+
Kapur (full image)	+	+	–	–	–	–	+	+	–	+
Otsu (*N*=20)	+	–	–	–	–	–	–	–	–	+
Kapur (*N*=20)	+	–	–	+	–	–	+	+	+	–
Otsu (*N*=50)	+	–	–	–	–	–	–	–	–	+
Kapur (*N*=50)	+	–	–	+	+	–	+	+	–	+
Otsu (*N*=100)	+	–	–	–	–	–	–	–	–	+
Kapur (*N*=100)	+	+	–	–	–	–	+	+	+	+
Otsu (*N*=200)	+	–	–	–	–	–	–	–	–	–
Kapur (*N*=200)	+	+	–	+	–	–	+	+	–	+
Otsu (*N*=500)	+	–	–	–	–	–	–	–	–	+
Kapur (*N*=500)	+	+	–	–	–	–	+	+	+	+
Otsu (*N*=1000)	+	–	–	–	–	–	–	–	–	+
Kapur (*N*=1000)	+	+	–	–	–	–	–	+	+	+

An example of such an image with its binary version obtained using block based adaptive Otsu thresholding, allowing the recognition of the QR code, is shown in Fig. 4.



(a) (b)

Fig. 4. Exemplary image with unrecognized QR code and its binary version allowing its proper recognition.

A similar image has also been obtained using the block based adaptive Kapur binarization.

IV. CONCLUSIONS

The proposed approach to fast estimation of image histogram for the binarization of images using various colour spaces allows to increase the recognition accuracy of the QR codes visible on many images acquired in different lighting conditions. As a result of the application of the Monte Carlo method it is possible to check several possible colour representations and utilize the simplified estimation of the histogram for Otsu and Kapur binarization which is an important element of the QR codes recognition process.

Due to the proposed novel statistical approach with the parallel implementation of fast binarization in various colour spaces, the QR recognition accuracy can be significantly improved as the verification of various binarization methods and colour conversions can be made at the same time.

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