Retrieving Images from Low-bit Representations With Use of Convolutional Neural Networks

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Abstract. In this paper we present the preliminary results obtained in the task of reversing the operations of image quantization (we take into account optimal Lloyd-Max quantization and uniform quantization with Floyd-Steinberg dithering) and halftoning with use of convolutional neural networks (CNN) based approach and deep learning techniques. In order to verify the effectiveness of the proposed algorithm we made the experimental analysis based on exemplary test images involving popular objective image quality measures in the form of Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM). Moreover, the resulting images were analyzed by taking into account their subjective visual examination. The results obtained within the experiments are properly commented and the final conclusions are drawn. The experimental analysis allows to state that the proposed CNN based approach allows for quality improvement and as such it can be used in practical applications of image retrieval from their low-bit representations.

Keywords: Image retrieval· dithering· halftoning· CNN

1 Introduction

The following image processing operations: halftoning, dithering and quantization [1], are used in computer systems to reduce the amount of gray shades in images for the tasks of image compression, presentation of images on low-quality displays and image printing. Since such operations highly reduce the amount of information contained in an image, the task of their reveral is in general an ill-posed problem. However, it was shown in [2] on example of halftoning that convolutional neural networks (CNNs) can greatly contribute in this area allowing to obtain better results than classical methods. In this paper we present the preliminary results obtained with the use of CNNs applied to reversing the mentioned operations. The main contributions of our work are: (I) applying CNN with simpler structure than in [2], (II) extending the analysis to quantization and dithering when compared to reverse halftoning addressed in [2].

2 Low-bit image representations

Halftoning - it is the operation of image sampling and its representation in the form of black and white dots of different sizes dependent on the grayscale values present in the specific areas of an image. It is parametrized by the distance between the dots. In our experiments we consider distance values of 4, 6 and 8.

Quantization - in our paper we consider the optimal Lloyd-Max scalar quantization of input image to the given number of 2, 4 or 8 levels of grayscale.
Dithering - is the operation of image quantization with prior addition of pseudorandom noise. The main role of the noise is to reduce the contouring effects. We considered scalar quantization to the following values of 2, 4 and 8 levels.

3 Network architecture

In our experiments we used CNN with the following topology: (I) two-dimensional convolutional layer (Conv2D) with 64 filters of size 7 on 7, (II) Conv2D layer, 32 filters, size 5 on 5 elements, (III) Conv2D layer, 32 filters, 3 on 3 elements, (IV) Conv2D layer, 32 filters, 3 on 3 elements, (V) Conv2D layer, 1 filter, 11 on 11 elements. In layers (I) - (IV) we used ReLU activation function. The last layer used linear activation function. In all layers we used bias. At input and output we expect grayscale images.

4 Experimental results

In our experiments we trained the CNN with 25 face grayscale images of resolution 512 on 512 pixels taken from the dataset [3] by using Adam optimizer and SSIM measure as the loss function. At the input we provided the low-bit representation of an image demanding its full reconstruction to the original grayscale image at output. Another 25 images from the same dataset acted as the training set with additional four standard test images: lake.bmp, lena.bmp, man.bmp and mandrill.bmp. The obtained results for: (I) halftoning with dots distance 4, 6 and 8, (II) Lloyd-Max quantization to 2, 4 and 8 levels, (III) dithering with Floyd-Steinberg method to 2, 4 and 8 levels are presented in Tables 1-3. One should note that in case of face images we show averaged results.

Table 1. Reversing image halftoning operation

Image(s)	PSNR [dB]	SSIM	PSNR [dB]	SSIM	PSNR [dB]	SSIM
	dist. 4		dist. 6		dist. 8	
faces	31.66	0.730	31.65	0.734	31.47	0.703
lake.bmp	30.40	0.708	30.29	0.698	30.20	0.655
lena.bmp	32.26	0.805	32.34	0.804	31.99	0.771
man.bmp	30.36	0.684	30.34	0.689	30.14	0.625
mandrill.bmp	29.27	0.535	29.26	0.554	29.11	0.432

The results depicted in Fig. 1 enable to observe that the CNN based approach allowed to reverse halftoning operation generating results which can be subjectively stated as more pleasing to the eye of an observer even if they are relatively soft and luck their original crispness and sharpness. The analysis of objective measures (see Table 1) shows results close to 30 dB and higher in case of faces images or Lena image (here even higher than 32 dB). The value of SSIM was higher than 0.800 only in one case of Lena image.

Reversing optimal Lloyd-Max scalar quantization results in images that can be characterized by higher sharpness (see Fig. 2). Although this operation may

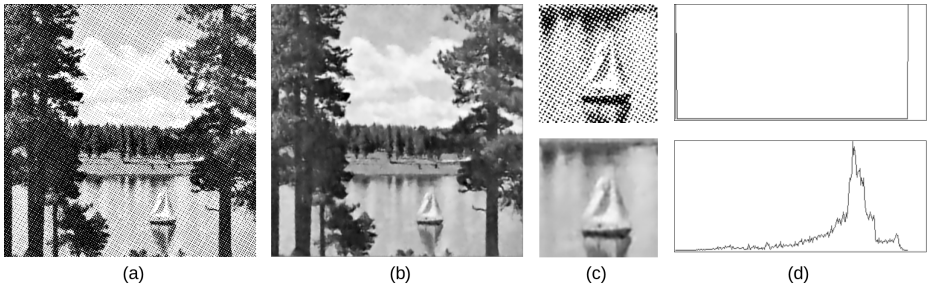

Fig. 1. Results in reverse halftoning for distance between dots equal to 4: (a) halftoned, (b) reconstructed, (c) exemplary fragments of images, (d) histograms of images

make more information to be irrevocably lost (see clouds in Fig. 2). However, the better sharpness is reflected also in the objective measures resulting in higher values of SSIM index while PSNR values do not conform this tendency. It should be noted that PSNR and SSIM measures have different theoretical background.

Table 2. Reversing image Lloyd-Max scalar quantization

Image(s)	PSNR [dB]	SSIM	PSNR [dB]	SSIM	PSNR [dB]	SSIM
	levels 2		levels 4		levels 8	
faces	28.44	0.605	29.81	0.758	32.42	0.858
lake.bmp	28.33	0.597	29.46	0.763	31.90	0.868
lena.bmp	28.39	0.674	30.37	0.817	33.31	0.889
man.bmp	28.41	0.497	29.38	0.727	31.85	0.874
mandrill.bmp	28.67	0.486	29.51	0.735	31.15	0.889

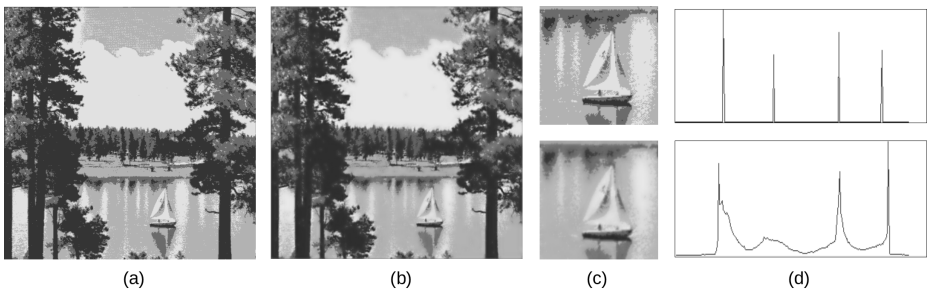

Fig. 2. Results in reversing Lloyd-Max scalar quantization for 4 levels: (a) quantized, (b) reconstructed, (c) exemplary fragments of images, (d) histograms of images

Both subjective and objective results obtained in this part of the experimental analysis prove that reversing the Floyd-Steinberg dithering operation allows to obtain the best results among the considered cases. It can be concluded that dithering operation, though uses the same level of shades as optimal Lloyd-Max scalar quantization, allows to convey much more relevant information contained in an image. Here, the obtained PSNR results are higher than 30 dB for all of the tested images (for levels number higher than 2) and the PSNR values for the Lake image are even higher than 36 dB. Also with SSIM index it was possible to

Table 3. Reversing image dithering operation

Image(s)	PSNR [dB]	SSIM	PSNR [dB]	SSIM	PSNR [dB]	SSIM
	levels 2		levels 4		levels 8	
faces	28.59	0.690	32.43	0.824	34.08	0.870
lake.bmp	29.48	0.757	34.36	0.891	36.41	0.926
lena.bmp	29.03	0.642	31.48	0.839	33.02	0.901
man.bmp	28.87	0.628	30.32	0.817	30.96	0.877
mandrill.bmp	29.51	0.676	32.87	0.797	34.03	0.840

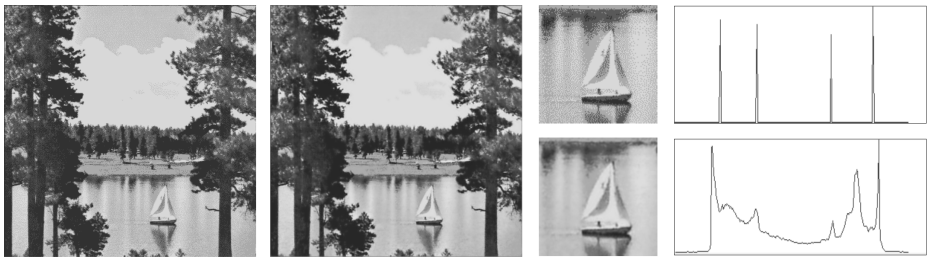

Fig. 3. Results in reversing Floyd-Steinberg dithering for 4 levels: (a) dithered, (b) reconstructed, (c) exemplary fragments of images, (d) histograms of images

obtain higher results even exceeding the level of 0.900 in case of the Lake image. Please note, however, that if one would like to compare the resulting images for the same level of shades of grayscale in all the cases (which is should be 2) then the halftoning operation was the one that keeps the most relevant information related to image details.

5 Conclusions

Based on the conducted experiments it can be concluded that the CNN based approach allows to reverse the operations of image halftoning, scalar quantization and dithering giving the results which can be more adequate for further presentation or archiving of images. This result is solely based on both subjective and objective quality measures. Since the presented results are preliminary we can say that the direction of the future work should be focused on experiments aimed at finding the CNN with the simplest topology understood in the sense of the number of parameters and computational complexity, yet, allowing to obtain the best possible results in image reconstruction.

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