Efficiency of image convolution

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***Abstract*—The article discusses the main algorithms used to convolve a digital image, experiment is performed on various reduction factors, and discusses the use of convolution algorithms for an image with a large number of fine details, analyzes the effectiveness of the experimental results and selects the most effective convolution algorithms used for images with a large number small parts.**

Keywords—Convolution, Image Processing, Algorithm, Small Parts, Effectiveness analysis

I. INTRODUCTION

Digital image convolutions are widely used in modern photo editors for image representation and scale optimization [4]-[6]. For the same purposes, they can be used in pattern recognition systems at the stage of preliminary processing [1]-[3]. When working with convolutional neural networks (CNN) [7]-[8], such algorithms are widely used to prepare input data. And also to optimize the time of data transmission via communication channels in various conditions of network operation [9]-[11]. After analyzing, we can say that a large number of various image convolution algorithms are currently used [4], [12]. Each algorithm due to its features gives different results for different types of images.

Based on the foregoing, it is important that the tasks of analyzing the efficiency of data representation [13], [14] and the application of image convolution algorithms containing linear and small-sized objects on the verge of resolution [4], [15] are relevant. And it will be relevant to develop practical recommendations on the use of such algorithms, mainly in the selection of the image convolution factor.

It is well known that on a halftone image various defects are noticeable much better than on color. That's why before using the image is converted to a halftone model. There are various ways to convert a color image to a halftone [4], [5].

In the YUV and YIQ color spaces used in PAL and NTSC, brightness I is calculated as

$$I = 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B. \quad (1)$$

In the transition between color spaces (for example: RGB → HSI) the formula of the average is used

$$I = \frac{1}{3} \cdot (R + G + B). \quad (2)$$

since the brightness of a digital image takes integer non-negative values, it is necessary to round the result to the integer.

At the same time, to take into account the peculiarities of image perception by the human eye in the HDTV model [17], coefficients for color spaces are different from those that used in the YUV and YIQ.

$$I = 0.2126 \cdot R + 0.7152 \cdot G + 0.0722 \cdot B. \quad (3)$$

The choice of the rule for obtaining a grayscale image for the purposes of work is not significant. By default, the rule (1) is used to convert an image to a halftone format.

II. EXPERIMENT PLANNING

The first step is to convert the image into a halftone model.

978-1-7281-1814-7/19/31.00

After that, you need to select the scaling ratio of the image. After analyzing the current state of the issue [4], [7], it is obvious that most often used coefficients are 2 and 3. When using CNN, as a rule, factor 2 is used for a smooth iterative scaling of the image by 2, which gives the minimum degree of smoothing small details. In classical systems, most often, factor 3 is used, which makes it possible to adequately take into account the position of the pixels of objects and lines in the vicinity of its center.

In carrying out the experiment, the coefficients 2 and 3 will be considered. In addition, the use of the coefficient 4 to analyze the degree of smoothing / disappearance of fine details in the picture will be considered. And confirmation of the fact that a two-time scaling of the image is 2 times better than a one-time scaling of 4 times.

Next, select the type of convolution. For the experiment, six convolution algorithms will be implemented. According to different sources, each of them is more or less suitable for a particular type of image. For the purposes of the work, let us consider how suitable they are for working with lines and fine details.

The paper discusses the following types of convolutions.

a) Brightness of the central pixel of the area

$$f' = f(\xi, \eta),\quad \xi = \lfloor x_{min} + 0.5 \cdot [x_{max} - x_{min}] \rfloor,\quad \eta = \lfloor y_{min} + 0.5 \cdot [y_{max} - y_{min}] \rfloor \tag{4}$$

$x_{min}, x_{max}, y_{min}, y_{max}$ – pixel coordinates of the considered area.

b) Average

$$f' = av = \frac{1}{n} \cdot \sum_{i=1}^{n} f_i, \tag{5}$$

f_i – the brightness of the pixels in the considered area of total number n.

c) Brightness closest to the average in the area

$$f' = \arg(\min |f_i - av|),\ i = 1,...,n, \tag{6}$$

f_i – the brightness of the pixels in the considered area of total number n.

d) Truncated average

$$f' = \frac{1}{n-2k} \cdot \sum_{i=1+k}^{n-k} f_i,\ 2k < n, \tag{7}$$

for values $k = 1$ and $k = 0.25n$, f_i – the brightness of the pixels in the considered area of total number n.

e) Median of brightness in the area

$$f' = me\{f_i\}, i = 1,...,n, \tag{8}$$

f_i – the brightness of the pixels in the considered area of total number n.

f) Average on the set of brightnesses - closest to the luminance of the central pixel in the considered area

$$f' = av_m = \frac{1}{m} \cdot \sum_{i=1}^{m} f_i, \tag{9}$$

f_i – the closest brightness to the center of the area of total number m.

It can be seen that some of the considered convolutions are non-adaptive, since they always replace the brightness distribution in the area with a predetermined brightness value. At the same time, other convolutions make it possible to obtain a new brightness value taking into account the brightness distribution in the vicinity.

To know how significant this can be it is needed to set up an experiment: for given coefficients (2, 3 and 4) for reducing the image scale, apply the described 6 types of convolutions and analyze the results obtained.

Results are analyzed on a qualitative and quantitative level.

On the quantitative level - by increasing the level of brightness uniformity in the interior, $K_H = Hold/Hnew$ and increasing contrast $K_C = Hnew/Hold$ on the border of the object with the background, where

$$H = \max |f_i - f_j|;\ f_i \neq f_j;\ i, j = 1, \ldots, n, \tag{10}$$

f_i – the brightness of the pixels in the considered area of total number n.

III. Experiment Results Analysis

In accordance with the experiment plan described earlier, an image containing small details was taken [16]. In particular, the image contains a large number of small details, including a pillar in the background, car numbers, etc.

The first experiment that was carried out was to reduce the image scale using 6 types of convolution with scaling factor of 2. The results are shown in Fig. 2-7.

Fig. 1. Brightness of the central pixel of the area

Fig. 2. Average

Fig. 3. Brightness closest to the average

Fig. 4. Truncated average

Fig. 5. Median of brightness

Fig. 6. Average on the set of m brightnesses

The next scaling factor was chosen 3. The results obtained for this factor can be seen in Fig. 7-12.

Fig. 7. Brightness of the central pixel of the area

Fig. 8. Average

Fig. 9. Brightness closest to the average

Fig. 10. Truncated average

Fig. 11. Median of brightness

Fig. 12. Average on the set of m brightnesses

For the third experiment, a scaling factor of 4 was chosen. The results of the third experiment are presented in Fig. 13-17.

Fig. 13. Brightness of the central pixel of the area

Fig. 14. Average

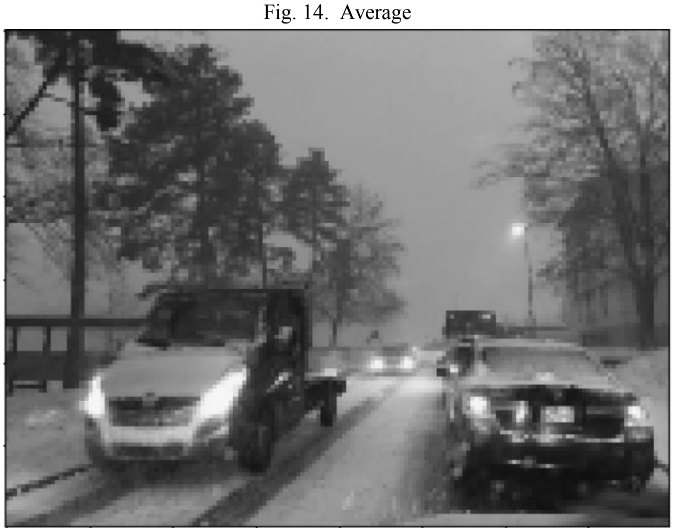

Fig. 15. Brightness closest to the average

Fig. 16. Truncated average

Fig. 17. Median of brightness

In order to be able to assess at the quantitative level, a table was created for each of the three scaling factors. Each table contains indicators of the level of uniformity of brightness and contrast for all 6 types of convolution.

TABLE I. TABLE OF RESULTS FOR SCALE FACTOR 2

Convolution	**Measure of quality**	
Level of quality	K_H	K_C
a) Brightness of the central pixel	1	3.1
b) Average	1	2.59
c) Brightness closest to the average	1	1.90
d) Truncated average	1	2.62
e) Median of brightness	1	1.70
f) Average on the set of brightnesses	1	1.58

TABLE II. TABLE OF RESULTS FOR SCALE FACTOR 3

Convolution	Measure of quality	
Level of quality	K_H	K_C
a) Brightness of the central pixel	1	3.062
b) Average	1.217	2.62
c) Brightness closest to the average	1	2.87
d) Truncated average	1.217	2.65
e) Median of brightness	1	2.87
f) Average on the set of brightnesses	1	2.22

TABLE III. TABLE OF RESULTS FOR SCALE FACTOR 4

Convolution	Measure of quality	
Level of quality	K_H	K_C
a) Brightness of the central pixel	1	3.25
b) Average	1.0004	2.59
c) Brightness closest to the average	1	2.90
d) Truncated average	1.0004	2.66
e) Median of brightness	1	3.02
f) Average on the set of brightnesses	1	2.1

IV. CONCLUSION

As a result of the experiment, you can see that the boundaries of the objects look chopped and fuzzy, and using the example of a pillar, you can see that the straight lines a pillar has moved off. For a factor of 2, you can see that the use of certain convolutions can lead to a complete loss of information about the object (Fig. 5), and you can also see the appearance of additional noise (Fig. 3 and 6). For coefficients 3 and 4 details(pillar) remained without distortion, but the designation of vehicle numbers was noticeably blurred.

After checking tabular results definitely can said that all three coefficients showed the preservation of the level of homogeneity. Convolution algorithms of the truncated average and arithmetic average, shows us that indicator of the level of homogeneity increased for the coefficients 3 and 4. On the side of the contrast index, one can notice a consistently high value for the brightness algorithm of the average pixel, this algorithm showed itself well on all coefficients. Worst result showed an algorithm of average on the set of brightnesses. At the same time, on coefficients 3 and 4, the median and brightness algorithms closest to the average distinguished themselves by high values. In general, the numbers of the coefficients 3 and 4 are higher(which is better) than for the convolution with a factor of 2.

Thus, the best results of the convolution of the image are achieved by using averaging convolutions(Average algorithm and Truncated average) and reducing the image using the coefficients of 3 or 4.

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