QUALITY ASSESSMENT MEASURE BASED ON IMAGE STRUCTURAL PROPERTIES

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ABSTRACT

In this paper, a new objective quality assessment measure for images is proposed based on statistical structural image analysis using Weibull model and Cramer-von Mises statistics. It is estimated via proximity of parameters of empirical distributions of a gradient magnitude of pixel intensities. Results of numerical experiments demonstrate that the proposed measure is more adequate to perception by human visual system than the usual pixel-by-pixel measures. Unlike other quality assessment measures, a new one can be used on not well-aligned images or on images having different sizes.

1. INTRODUCTION

During image capture and processing digital image is a subject of multiple degradations, such as noise, blur, compression artifacts, etc. It is very important to use an appropriate measure of image quality in order to quantify these degradations as well as to quantify performance of various image processing methods applied in order to suppress these degradations (e.g., various image restoration methods). Despite great efforts made recently in development of image objective quality measures, the problem is far from being completely solved.

Most of existed objective quality measures are based on computing average values of a point-by-point divergence of pixel intensities of two images, one of which is considered as an original image, and another one is a distorted image caused by a transfer via communication channel or a digitally manipulated image resulting by application of some image processing procedure.

It is a common practice in digital image processing applications to use as a proximity measure of image mean square deviation, the peak signal to noise ratio (PSNR) and others. However, these simple measures show very often an inadequacy of estimations, received on their basis, to the results of visual inspection. One may find many examples of such pair of images, which similarity is obvious from human visual system (HVS) point of view, but PSNR and other objective quality measures show unacceptable low similarity. Additionally, these measures work only for cases of well-aligned images of the same size. Well-grounded analysis and discussion of these problems can be found in [1].

Recently, many quality assessment measures have been developed utilizing some structural information from an image [2-5]. However, it is extremely important to concretize the concept of a "structure".

In [4], a so-called "universal image quality index" (QI) was introduced. The idea of QI is based on simultaneous determination of three types of proximity measures of images, including the most used measure - the correlation coefficient. This paper has provoked an impulse of scientific investigations in this direction resulting in improvement of QI. In what follows, a measure of structural similarity [5] has been developed, that compares local patterns of pixel intensities that have been normalized for luminance, contrast and mean structural similarity index (MSSIM) to evaluate the overall image quality. In [6-8], PSNR-HVS-M, a modification of PSNR, was proposed. This measure takes into account the contrast sensitivity function. It outperforms many well-known reference based quality metrics and demonstrates high correlation with the results of subjective experiments.

In this paper, a model of the image structure for quality assessment based on a set of image edges found by gradient methods is proposed. The idea to use edge information for image quality assessment is not a new one (see, e.g., [9]). However, in existed approaches a similarity of structure of edge maps was determined on the base of the point-by-point divergence determination.

In a contrary to this, in this paper, we use the methods of statistical analysis of a set of edges, assuming that the numerical value of gradient magnitude is modeled by the Weibull distribution. The structural similarity of images is estimated by proximity of parameters of the appropriate distributions.

For an illustration of efficiency of the proposed approach, the results of the numerical experiments with application of gradient methods are given.

2. METHOD

Let I be an image of size $M \times N$ with elements $I(m,n)$; $m = 0,1,...,M-1$; $n = 0,1,...,N-1$.

One of the concepts describing the structure of images is the concept of a map of image edges, which represents the virtual curves dividing the parts of the image having different brightness levels. There are many methods of edge detection. In this paper, we will only apply the gradient methods, which determine for each pixel the gradients of brightness both in horizontal and

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vertical directions, and also the gradient magnitude. The large values of gradient magnitude specify that the given pixel is located on an edge.

Let $G_H(m,n)$ and $G_V(m,n)$ at a point (m,n) of an image be the horizontal and vertical gradients, determined by one of known gradient methods.

The main assumption here we make is that the set of pairs $(G_H(m,n), G_V(m,n))$ adequately enough describe the structural properties of image I and can be considered as a two-dimensional random variable. In the present paper we will be limited by consideration of the gradient magnitude $G(m,n)$, which is given by formula

$$G(m,n) = \sqrt{G_H^2(m,n) + G_V^2(m,n)}\ . \qquad (1)$$

We suppose that the gradient magnitude (1) is a random variable with Weibull distribution density

$$f(x;b,c) = \frac{c}{b}\left(\frac{x}{b}\right)^{c-1} \exp\left[-\left(\frac{x}{b}\right)^{c}\right], \qquad (2)$$

where b denotes a scale parameter, and c denotes a form parameter, $x \geq 0, b > 0, c > 0$.

As a measure of structural proximity of two images with probability distribution functions of gradient magnitude $F_1(x;b_1,c_1)$ and $F_2(x;b_2,c_2)$ accordingly, we accept

$$W^2 = \frac{\min(b_1,b_2)\min(c_1,c_2)}{\max(b_1,b_2)\max(c_1,c_2)},\ 0 \leq W^2 \leq 1. \qquad (3)$$

The measure (3) is a simple transformation of more complicated statistics of Cramer-von Mises used for estimating of a divergence of two distributions. In this case the greater proximity of images, the greater are values of a measure (3).

Thus, the following algorithm for image quality assessment is proposed:

1. Determine the gradient magnitude $G(m,n)$ for each image by formula (1), where the gradients $G_H(m,n)$ and $G_V(m,n)$ are calculated by one of known gradient methods.

2. Histograms of magnitude for both images are determined, and the form and scale parameters of Weibull distribution adjusted under the appropriate histograms are estimated.

3. The proximity measure of images using formula (3) is calculated with substituted values of obtained estimations of parameters $b_j, c_j;\ j = 1,2$.

In the paper we apply the gradient method, based on Sobel masks (without the threshold operations, which are usually carried out for final allocation of edges). The parameters of Weibull distribution and the measure W^2 are determined by means of package STATISTICA. The values of PSNR-HVS-M are calculated by Matlab source given in [8] and MSSIM values by [5].

3. EXPERIMENTS

To check efficiency and to reveal advantages of the proposed method, the series of numerical experiments are carried out.

Experiment 1. First we execute easily reproducible experiment with revealing the greater conformity of a proximity measure (3) to HVS, than of formal criteria based on pixel-by-pixel analysis of an intensity divergence.

From an arbitrary image of size $M \times N$ we "cut-out" two new images of smaller sizes. The first image contains all pixels of original image, except last K rows and last L columns, whereas the second one contains all pixels, except first K rows and first L columns. If M and N are large enough and $K << M$, $L << N$, all three images (an original and two formed from it) will be perceived by HVS as identical. However, PSNR between new images can accept rather low values, revealing their significant divergence. For example, for the known standard image "Baboon" of sizes 512×512 after reduction by above mentioned way up to 510×510 we have $PSNR \approx 18.5$ dB, i.e. by the given criterion they are essentially different images. To the same conclusion we come by analyzing the value of mean square deviation, which is equal to 30, and MSSIM, with the value ~0.229. Meanwhile, parameters of Weibull distribution for these images are practically coincided, and $W^2 = 0.998$, i.e. it is possible to conclude, that there is no structural distinction in images in this example.

For images “Baboon” and “Baboon-msk” with masked noise from [8] we have PSNR=26.2 dB, PSNR-HVS=34.4 dB, PSNR-HVS-M=51.7 dB, MSSIM=0.882, $W^2 = 0.922$.

Comparing images rotated from each other on 90 degrees we obtain that the parameters of Weibull distribution are completely coincide, while PSNR and other measures can specify the large distinction in images. Such distinction between criterion W^2 and perception of HVS shows that the last is based on the information, carried by the contents and structure of the considered image.

Experiment 2. Random distortions of an image. The standard image “Lenna” of size 512×512 was degraded by a method of numerical modeling and addition to intensity of pixels additive normal noise with variance σ^2. Then there were determined empirical distribution of probabilities of gradient magnitude of both initial and noisy images, and also there were estimated parameters of appropriate Weibull distribution and value of a measure W^2 as well. The divergence of the received images from the original was determined by means of the various measures which are mentioned above. Results are given in Table 1.

The analysis of Table 1 shows that PSNR rather sensitively reacts to changes of the image quality, though the visual analysis of image shows that the structural information of the given image practically does not vary. The proposed measure W^2 detects some changes of structural information, at that on change of quality reacts, basically, the form parameter c. Note that MSSIM also detects the structural changes of images, but more “intensively” than W^2.

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σ	Quality measure					
	PSNR (dB)	PSNR-HVS-M (dB)	MSSIM	Parameters of Weibull distr.		W^2
				c	b	
0	∞	∞	1.000	25.48	1.315	1.000
2	41.8	46.0	0.967	26.19	1.351	0.947
4	36.1	40.2	0.887	27.41	1.412	0.866
6	32.7	36.3	0.792	29.56	1.485	0.764
8	30.3	33.5	0.696	32.27	1.556	0.668
10	28.4	31.4	0.612	32.87	1.622	0.629
12	26.9	29.7	0.538	32.13	1.689	0.618
14	25.6	28.2	0.475	36.36	1.738	0.530
16	24.5	27.0	0.423	38.39	1.790	0.488
18	23.5	25.9	0.378	42.01	1.832	0.435
20	22.6	24.9	0.340	43.20	1.878	0.413

Table 1. Dependence of different proximity measures on σ .

JPEG quality parameter	Quality measure					
	PSNR (dB)	PSNR-HVS-M (dB)	MSSIM	Parameters of Weibull distr.		W^2
				c	b	
100	∞	∞	1.000	48.79	1.450	1.000
90	37.1	62.8	0.974	49.12	1.455	0.990
80	32.6	56.2	0.943	48.92	1.451	0.996
70	30.5	51.0	0.919	49.14	1.448	0.991
60	29.1	47.6	0.899	49.51	1.446	0.983
50	28.2	45.0	0.881	48.32	1.444	0.986
40	27.4	42.1	0.860	48.09	1.440	0.979
30	26.4	38.8	0.831	46.33	1.434	0.939
20	25.3	34.0	0.783	43.22	1.425	0.871
10	23.4	26.7	0.681	41.92	1.365	0.809

Table 2. Dependence of different proximity measures on compression rate by JPEG standard.

Experiment 3. Image compression. In the given series of experiments the compression of images by JPEG standard was carried out, changing the quality parameter of image compression over a wide range. As an example standard image "Baboon" of size 512x512 was used. Results are given in Table 2.

Analysis of Table 2 results to the similar conclusions as at random distortions of the image.

Experiment 4. Proximity estimation for images of different sizes. The results of images proximity determination by the offered method to the results received by other methods mentioned above cannot be compared, as these methods work only for the identical sizes of compared images. The given experiment was made for images and their down-sampled versions. The results are given in Table 3.

It can be seen that despite size difference there is a large enough proximity of considered images. Similar results are obtained also for images one of which is obtained after a rotation to a certain angle.

Image	Size 256x256		Size 512x512		W^2
	Parameters		Parameters		
	c	b	c	b	
Lenna	27.23	1.170	25.48	1.315	0.832
Baboon	60.25	1.538	48.79	1.450	0.764
Cameraman	23.66	0.954	20.92	1.077	0.783

Table 3. Dependence of proximity measure W^2 on image sizes.

We shall note that the carried out experiments do not exhaust all the areas of applications of the proposed measure of proximity. Especially, it is necessary to emphasize an opportunity of application of this measure in automatic systems of image processing.

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4. CONCLUSION

In this paper, we have proposed a measure of proximity of images based on their structural similarity. It is based on statistical distribution of gradient magnitude, which characterizes image edges. As a model for gradient magnitude the Weibull distribution is used.

The proximity of empirical distributions is estimated on proximity of parameters of empirical distributions of gradient magnitude, obtained at their adjustment to Weibull distribution.

Series of the numerical experiments are executed showing that the proposed measure of proximity of images is more adequate to perception by HVS than the conventional pixel-by-pixel measures such as PSNR. The new measure is compared with PSNR-HVS-M and MSSIM on examples of images corrupted by an additive noise, and those compressed by JPEG. It is shown that the measure proposed in this paper is applicable to not well-aligned images and to images having different sizes.

5. ACKNOWLEDGMENTS

This work was supported by the Academy of Finland, Project No.213462 (Finnish Centre of Excellence Program in Research 2006-2011).

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