MODERN METHODS FOR IMAGE QUALITY ASSESSMENT

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Abstract: This paper deals with the comparison of Image Quality Assessment (IQA) algorithms. The test gallery of colour calibre images were captured for comparison of IQA algorithms. Test gallery was captured by two cameras with a different type of sensors – CMOS with Bayer mask and a Foveon sensor.

Keywords: Image Quality Assessment, Mean Squared Error, Peak Signal to Noise Ratio, Universal Quality Index, Structural Similarity Index, Edge Strength Similarity

1. INTRODUCTION

Image Quality Assessment (IQA) algorithms are very useful instrument to compare image quality. This paper is devoted to the comparison of IQA algorithms which are focused on structural and brightness differencies between images. Algorithms are tested on the real problem which is a comparison of two camera sensors with optical colour calibre. The first camera is Nikon D3100 with CMOS sensor and the second camera is Sigma DP2 Merill, which has Foveon sensor. Test images of these two cameras were compared to a synthetic image of an optical calibre which has defined colours in RGB space.

2. IMAGE QUALITY ASSESSMENT ALGORITHMS

Image Quality Assessment (IQA) algorithms [1] can be divided into three parts according to the use of reference image. The first parts of these algorithms are algorithms which don't use reference image (No-Reference IQA - NR-IQA). The second part is a group of algorithms that using part of the reference image or extracted features of the reference image and third part are algorithms that use the whole reference image. This article is focused on that part of IQA algorithm which uses the whole reference image.

2.1. MEAN SQUARED ERROR (MSE)

This algorithm [1] computes mean squared error of the tested image with the reference image. Very easy computation is an advantage of this algorithm but there is a slightly similarity with human visual system assessment of image quality. The MSE is calculated as (1)

$$MSE(f,g) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left[f(x,y)-g(x,y)\right]^2 \quad (1)$$

where *f(x,y)* is tested image, *g(x,y)* is the reference image, *x* is an index of pixel row, *y* is an index of pixel column and *MxN* is the size of both images. Lower result value means that the images are more similar.

2.2. PEAK SIGNAL TO NOISE RATIO (PSNR)

The PSNR algorithm [1] is principally similar to MSE algorithm with some extension. PSNR is calculated as (2) or as (3)

$$PSNR(f,g) = 10\log_{10}\left(\frac{\left(2^B - 1\right)^2}{\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left[f(x,y) - g(x,y)\right]^2}\right) \tag{2}$$

$$PSNR(f,g) = 10\log_{10}\left(\frac{\left(2^B - 1\right)^2}{MSE(f,g)}\right) \tag{3}$$

where B is the bit depth of images. The result value can acquire values ≥ 0 where 0 means that images are the same. Because of the PSNR algorithm is based on MSE this algorithm is slightly similar to human visual system assessment of image quality too.

Higher result value means that the images are more similar.

2.3. UNIVERSAL QUALITY INDEX (UQI)

The Universal Quality Index [2] measures change (decrease) of correlation between reference and tested images. UQI can be calculated as (4)

$$UQI(f,g) = \frac{4\sigma_{fg}\mu_f\mu_g}{\left(\sigma_f^2 + \sigma_g^2\right)\left(\mu_f^2 + \mu_g^2\right)} \tag{4}$$

where μ_f and μ_g are mean luminance of tested and reference images, σ_f and σ_g are standard deviations of these images and σ_{fg} is cross covariance between both images calculated as (5).

$$\sigma_{fg} = \frac{1}{N-1}\sum_{i=1}^{N}\left(f_i - \mu_f\right)\left(g_i - \mu_g\right) \tag{5}$$

UQI can acquire values between -1 and 1, where 1 is value which means that tested and reference images are the same.

This algorithm is in comparison with MSE or PSNR more similar to human visual system assessment of image quality.

2.4. STRUCTURAL SIMILARITY INDEX (SSIM)

The human visual system is highly adapted to obtain information from structural differences in image. The SSIM algorithm [1] striving to simulate this fact and assesses dependence between values of pixels in image, where can be found dependence on values which lies in their neighbourhood. The SSIM algorithm compares luminance, contrast and structural components of tested and reference images. This algorithm can be calculated as (6)

$$SSIM(f,g) = \left[l(f,g)\right]^{\alpha} \cdot \left[c(f,g)\right]^{\beta} \cdot \left[s(f,g)\right]^{\gamma} \tag{6}$$

where *l(f,g)* is luminance component, calculated as (7), *c(f,g)* is contrast component, calculated as (8), *s(f,g)* is structural component, calculated as (9), *f* is tested image, *g* is reference image and $\alpha>0$, $\beta>0$, $\gamma>0$ are constants, which means relative importance of these components.

$$l(f,g) = \frac{2\mu_f\mu_g + C_1}{\mu_f^2 + \mu_g^2 + C_1} \tag{7}$$

$$c(f,g) = \frac{2\sigma_f\sigma_g + C_2}{\sigma_f^2 + \sigma_g^2 + C_2} \tag{8}$$

$$s(f,g)=\frac{\sigma_{fg}+C_3}{\sigma_f\sigma_g+C_3} \quad (9)$$

The parameters μ_f and μ_g are mean luminance of tested and reference images, σ_f and σ_g are standard deviations of these images and σ_{fg} is cross covariance between both images calculated as (5). The constants C_1, C_2 and C_3 can be used to adjustment of equations in case those are expressions $\mu_f^2+\mu_g^2$, $\sigma_f^2+\sigma_g^2$ or $\sigma_f\sigma_g$ too close to 0 and are calculated as $C_1=(K_1L)^2$, $C_2=(K_2L)^2$ and $C_3=\frac{C_2}{2}$, where $K_1<<1$, $K_2<<1$ and L is dynamic range of one pixel (e.g. for 8bit grayscale image is $L = 255$).The result value of this algorithm is between 0 and 1, where value 1 means that images are the same.

2.5. EDGE STRENGTH SIMILARITY (ESSIM)

The ESSIM index [1] is based on fact that human visual system is more sensitive to direction which is in image represented by stronger edges. We can use e.g. high-pass filter to boost edges in the image and then extract edges with use of gradient operator (Sobel, Prewitt, etc.). Edge detection is used as horizontal and vertical and as diagonal detection. Higher value of these two is used as edge strength for every pixel. The ESSIM index is then calculated as (10)

$$ESSIM(f,g)=\frac{1}{N}\sum_{i=1}^{N}\frac{2E(f,i)E(g,i)+C}{(E(f,i))^2+(E(g,i))^2+C} \quad (10)$$

where f is tested image, g is the reference image, N is number of pixels in every image, $E(f,i)$ is edge strength of i-th pixel in tested image and $E(g,i)$ edge strength of i-th pixel in reference image. The parameter C is scale and is calculated as $C=(BL)^2$, where B is constant and L is dynamic range of edge strength.

The IQA based on ESSIM is very similar to human visual system assessment of image quality as well as SSIM. The result values can acquire same values as SSIM too.

3. COMPARISON OF IQA ALGORITHMS

Tested IQA algorithms have been compared on a real example problem. Images of colour optical calibre captured by Nikon D3100 (CMOS sensor with Baer mask) has been compared with images captured by Sigma DP2 Merill (Foveon sensor). The synthetic image of defined RGB values was used as the reference image for comparison of these test galleries.

The monolithic colour area (defined RGB code 255;171;14) was used in example results in this paper as reference image which has been compared with original images taken by two tested cameras.

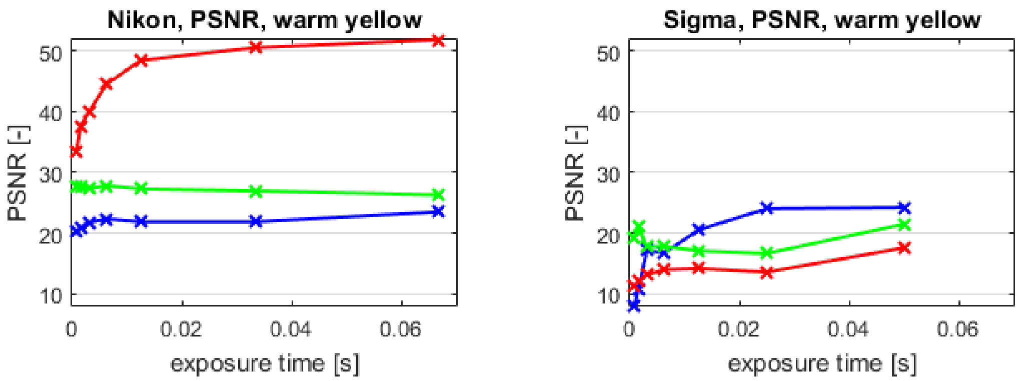
3.1. RESULTS

The output of MSE algorithm can be in some cases much higher than at other test images. The PSNR algorithm has the MSE output in a denominator. This is a reason why the extremely high MSE output values causes very small output values (Graph 1) of the PSNR algorithm. Thanks to this extremely changes, the outputs of these two algorithms have a very small dispersion of values.

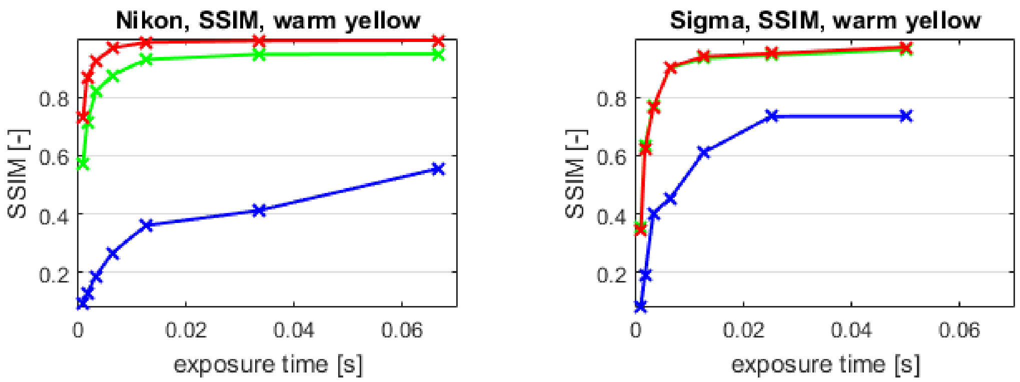
The UQI algorithm is very similar to the SSIM algorithm but has no correction constants. Because of that, this algorithm fails on images with mean luminance or standard deviations which are very close to zero or are zero. This is the case of one the tested synthetic image. The UQI algorithm returns only zero for calculations with this images.

The SSIM algorithm has against to UQI correction constants C_x and can fix problems with mean luminance or standard deviations which are very close to zero. Because of that output values of SSIM (Graph 2) are more stable and allow comparison of test images where one of which is the synthetic image.

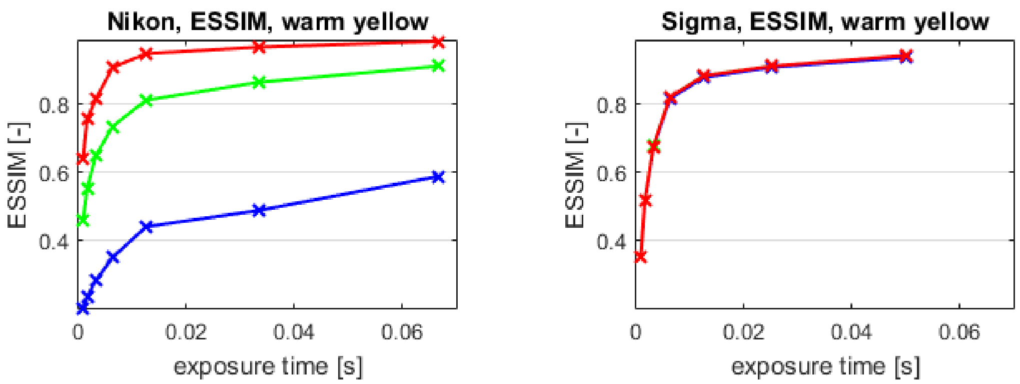
Algorithm of ESSIM type uses edge detectors to calculate the output. This fact can cause problems of distinguishing between areas in the test images that have monolithic colours or of synthetic images. The output values of ESSIM (Graph 3) are very similar to SSIM output in other causes.



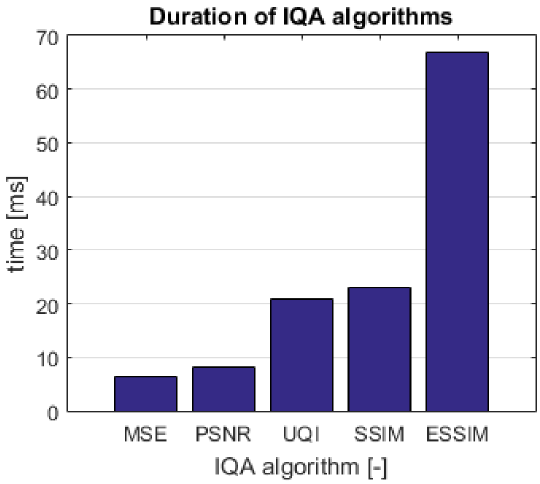
Graph 1: A graph of image quality according to exposure time, alg. PSNR, RGB channels



Graph 2: A graph of image quality according to exposure time, alg. SSIM, RGB channels



Graph 3: A graph of image quality according to exposure time, alg. ESSIM, RGB channels



Graph 4: Duration of IQA algorithms, average of 1008 repeats, image size 400x400 px, measured on CPU Intel Core i3-330M

Graph (Graph 4) shows average duration of tested IQA algorithms. Considering outputs of tested algorithms and time duration, the SSIM algorithm seems to be the best choice for comparison of synthetic and tested image combinations.

4. CONCLUSION

The MSE and PSNR algorithms are the fastest for computation. The UQI is almost as quickly as SSIM and ESSIM algorithm is significantly slowest. The UQI and ESSIM algorithms are not suitable for assesment of synthetic images or images with monolitic colours. The MSE and PSNR algorithms may have very small dipersion of output values so they are advantageous for simplier applications that are focused on speed. The SSIM algorithm has been chosen as the best solution for quality assessment of test image gallery. Duration of calculation and outputs of the SSIM algorithm had best results for my example problem.

Future work will be focused on No-Reference IQA algorithms and both of these types will be used as fitness functions of evolutionary algorithms in my dissertation thesis.

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