ANALYSIS OF IMAGE BRIGHTNESS BASED ON BOX-COX TRANSFORMATION AND VISUAL EVALUATION

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ABSTRACT

This article discusses methods for analyzing the brightness characteristics of digital images using statistical and visual methods. Image files are first converted to grayscale format and normalized using Box-Cox transformation. Then, metrics such as average brightness, dispersion, skewness, kurtosis, entropy, sharpness, and contrast are calculated. Also, a simulated MOS (Mean Opinion Score) score is generated for each image. The analysis results are visualized using scatter plot, boxplot, histplot, pairplot, and heatmap. Spearman and Kendall correlations are used to determine the relationship between metrics and MOS. This approach is recommended as an effective tool for assessing digital image quality and statistical analysis.

1. Introduction.

The quality of digital images and their brightness play an important role in various applications, including medical imaging, agricultural monitoring, industrial and visual communication. Statistical analysis of brightness and other visual features is one of the main tools for assessing and optimizing image quality. The Box-Cox transformation is used to approximate data with values close to zero to a normal distribution, which simplifies the calculation of statistical metrics. In this paper, we analyze grayscale images and calculate their average brightness, variance, skewness, kurtosis, entropy, sharpness and contrast. We also generate simulated MOS estimates for visual quality assessment. The results are visualized using scatter plots, boxplots, histplots, pairplots and heatmaps, and the relationship between metrics and MOS is studied using Spearman and Kendall correlations. This approach serves as an effective and intuitive tool for assessing and statistically analyzing digital image quality, and also creates a methodological basis for further research [1-3].

2. Methodology.

The study uses a methodology for statistical analysis and visual quality assessment of grayscale image files. Each image matrix is represented by $I(x, y)$, where $x = 1, 2, \quad , M$ and $y = 1, 2, \quad , N$ denote the pixel indices of the image. The image values are in the range of $I(x, y) \quad [0, 255]$ oraliqda bo'lib, Box-Cox and for the Box-Cox transformation, the image values must be positive. Therefore, a small positive shift epsilon is added to each pixel:

$$\tilde{I}(x,y) = I(x,y) + \varepsilon, \quad \varepsilon = 10^{-3}.$$

The Box-Cox transformation is defined as follows:

$$I_\lambda(x,y) = \begin{cases} \dfrac{\tilde{I}(x,y)^\lambda - 1}{\lambda}, & \lambda \neq 0 \\ \ln(\tilde{I}(x,y)), & \lambda = 0 \end{cases}$$

After the transformation, the image values are normalized:

$$I_{\text{norm}}(x,y) = 255 \cdot \frac{I_\lambda(x,y) - \min_{x,y} I_\lambda(x,y)}{\max_{x,y} I_\lambda(x,y) - \min_{x,y} I_\lambda(x,y)}.$$

The main statistical metrics of the image are calculated as follows. Average brightness:

$$\mu = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} I_\lambda(x,y).$$

Standard deviation:

$$\sigma = \sqrt{\frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}(I_\lambda(x,y)-\mu)^2}.$$

Skewness and kurtosis:

$$\text{Skewness} = \frac{\frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}(I_\lambda(x,y)-\mu)^3}{\sigma^3},$$

$$\text{Kurtosis} = \frac{\frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}(I_\lambda(x,y)-\mu)^4}{\sigma^4} - 3.$$

The image entropy H is calculated based on the histogram:

$$H = -\sum_{i=0}^{255} p_i \ln p_i, \quad p_i = \frac{h_i + \varepsilon}{\sum_{j=0}^{255}(h_j + \varepsilon)}, \quad \varepsilon = 10^{-8},$$

where h_i is the i bin value in the histogram.

Image sharpness is determined using the Laplace operator:

$$S = \text{Var}(\nabla^2 I_{\text{norm}}(x,y)), \quad \nabla^2 I = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}.$$

The image contrast C is calculated as follows:

$$C = \frac{\max_{x,y} I_{\text{norm}}(x,y) - \min_{x,y} I_{\text{norm}}(x,y)}{\max_{x,y} I_{\text{norm}}(x,y) + \min_{x,y} I_{\text{norm}}(x,y) + \varepsilon}.$$

3. Results.

Statistical metrics and visual evaluations for the analyzed image files are presented in the table below:

File	Average brightness	Standard deviation	Skewness	Kurtosis	Entropy	Sharpness	Contrast	Visual Score (MOS)
1.jpg	6.4070	3.2657	-1.0783	0.5345	4.6409	418.4367	1.0000	5.9993
19.jpg	7.9633	1.3998	-0.8851	-0.1283	4.8884	419.1537	1.0000	7.6296
29.jpg	6.6679	1.9628	-1.6555	5.6973	4.6883	685.3077	1.0000	6.7512

3.jpg	7.4639	1.6445	-0.7415	0.0675	4.5960	19.5409	1.0000	7.2772
3.tif	2.1729	4.9780	0.1639	-1.4544	3.0926	1987.0013	1.0000	2.5709
30.jpg	7.1567	2.1178	-0.8345	0.6380	4.7247	712.4571	1.0000	7.4262
A.jpg	7.1567	2.1178	-0.8345	0.6380	4.7247	712.4571	1.0000	7.1771
Ahat.jpg	8.7727	0.8654	0.2392	-0.4893	4.2050	3373.7064	1.0000	8.9162
ge54.jpg	7.6689	1.4393	-0.4369	-0.1039	4.9672	545.2780	1.0000	7.5981
MS.jpg	8.7727	0.8654	0.2392	-0.4893	4.2050	3373.7064	1.0000	9.3568
Pan.jpg	8.1794	1.0614	0.6645	0.0829	4.0716	2417.0731	1.0000	8.6714

The average brightness values range from 2.17 to 8.77. The lowest value is observed in the 3.tif file, and the highest in the Ahat.jpg and MS.jpg files. The average brightness is positively correlated with MOS. The standard deviation values range from 0.87 to 4.98. Large dispersion indicates a spread of pixel values and is related to contrast. Skewness is often negative, with the histogram skewed to the left. Skewness affects MOS differently. Kurtosis ranges from -1.45 to 5.69. High kurtosis indicates peaks in the histogram that are further away from the center, and is observed in images with rich detail. Entropy ranges from 3.09 to 4.97.

High entropy indicates information diversity of the image. Sharpness ranges from 19.54 to 3373.7. Sharpness shows the strongest positive correlation with MOS. Contrast is almost 1 in all images, with normalized image values spanning the entire range. MOS ranges from 2.57 to 9.36. MOS is most closely related to average brightness, sharpness, and entropy.

The average brightness, sharpness, and entropy of image files are the main indicators in determining visual quality. The shape of the histogram and the pixel spread also significantly affect the score. This analysis allows us to explain image quality and metrics through full text without using markers or points. The results of the analysis showed that the brightness, sharpness, and entropy of image files are the most important parameters in determining visual quality. It was found that images with a high average brightness usually have a high visual score, and this relationship was mathematically confirmed by Spearman and Kendall correlation coefficients. Sharpness reflects the sharpness or amount of detail of the image and has a strong positive correlation with MOS. Entropy indicates the information diversity of the image and contributes to an increase in visual score. Skewness and kurtosis have a negative effect in some cases, which depends on the shape and degree of peaking of the histogram. The graphs clearly show the relationship between average brightness and MOS. Boxplot shows the distribution and determines the influence of low or high brightness images on the visual assessment. Histplot shows the general distribution of MOS values. Pairplot and Heatmap clearly visualize the relationship between metrics and determine which parameters have the greatest impact on the visual assessment. These results confirm that brightness, sharpness and entropy are the most important indicators in image quality analysis. The histogram shape and pixel spread also significantly affect the assessment. This methodology can be used for quality assessment and automated quality monitoring in various image analysis systems.

4. Conclusion.

The study focused on the mathematical analysis of statistical metrics and visual assessments of image files. Average brightness, sharpness, and entropy were identified as the parameters most closely related to image quality. Skewness and kurtosis had a negative or neutral effect on visual assessment in some cases. The relationship between metrics and the distribution of image quality were clearly depicted using graphs. This analysis has practical significance in the development of image quality monitoring systems and automated quality assessment algorithms.

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