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Quadri-Histogram Equalization using cut-off limits based on the size of each histogram with preservation of average brightness

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Abstract The traditional methods of equalization based on the histogram increase the contrast of the images, at the expense of great changes in the average brightness of the image and loss of information, producing images with an unnatural appearance. Consequently, we desire to develop a technique of contrast enhancement that preserves the average brightness of the image and thus avoid the saturation levels that cause the loss of information. We present the Quadri-histogram Equalization with Limited Contrast (QHELC), an algorithm that divides the histogram into four subhistograms, which are equalized independently with bounds on the contrast improvement. These bounds are designed to constrain the distortion on the image, and our experimental results show that the proposed method preserves both the average brightness and the details of the images, compared to several methods found in the literature.

Keywords Contrast Enhancement · Loss of Information · Limited Contrast · Average Brightness · Equalization

1 Introduction

The most popular method for improving the contrast in digital images is the Histogram Equalization (HE). The popularity of HE is due to its simple implementation and its effectiveness when improving the contrast. However, for consumer electronic products such as: digital cameras, digital video cameras, televisions, among others, the application of HE is not the best alternative. This is because the HE introduces level saturation effects in small areas that might be of interest to the observer [1]. These saturation effects mainly produce these problems: degrade the appearance of the image and they lead to a large loss of information [2]. The HE produces a large change in brightness in the processed image, causing it to lose enough quality [3] and to be visually unpleasant. Consequently, the preservation of the average brightness of the image is an essential technique to avoid the loss of quality in the images. Kim [4] was the first to introduce the idea of preserving the average brightness of an image for consumer electronic products, with this idea, the effects of saturation are reduced and also prevents the unnatural appearance of the image [5]. In the literature we can find several effective equalization methods in terms of contrast enhancement based on preserving the average brightness. However, these methods also alter the average brightness of the image to a small extent and result in loss of information. Among these methods we can cite: *Brightness Preserving Bi-Histogram Equalization* (BBHE) [4], *Dual Sub-Image Histogram Equalization* (DSIHE) [6], *Minimun Mean Brightness Error Bi-Histogram Equalization* (MMBEBHE) [7], *Bi-Histogram Equalization with a Plateau Limit* (BHEPL) [5], *Bi-Histogram Equalization with Median Plateau Limit* (BHEPLD) [8], *Bi-Histogram Equalization using Three Plateau Limits* (BHE3PL) [9], *Bi-Histogram Equalization using Two Plateau Limits* (BHE2PL) [10] , *Brightness Preserving and Contrast Limited Bi-histogram Equalization* (BPCLBHE) [11]. In this work we propose a new method called Quadri-histogram Equalization with Limited Contrast (QHELC), which improves the input image, and in turn preserves both the average brightness and the details of the image. This method is a modified version of the BPCLBHE method [11], which further increases the number

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of subhistograms for the equalization process.

The article is organized as follows, in Section 2, the formulation for HE and a small description of the *Clipped Histogram Equalization* (CHE) are presented, since both techniques are the fundamental basis for the given proposal. In Section 3 the QHELC is presented and discussed. The experimental results are presented in the Section 4, and finally Section 5 presents the conclusion of the work.

2 Background

This section presents the two main techniques on which the proposed method is based: The Equalization of the Histogram and the CHE. The latter is a method that manages to better contrast the small objects in the image, since it allows to limit the rate of improvement that one wishes to achieve.

2.1 Histogram Equalization

Let I be an image of dimension $M \times N$ pixels, where $I(x,y)$ represents the brightness of a pixel inside the I image, and (x,y) the coordinates of the pixel within the same image, the histogram H corresponding to the image that describes the frequency of the values of gray levels that appear in the image, is defined as:

$$H(q) = n_q, \tag{1}$$

where $q = 0, 1, ..., L-1$. L represents the maximum amount of levels that exists in an image, n_q represents the number of times the intensity q appears in the image and $I(x,y) = q$. The probability of occurrence of the $q-th$ intensity $p(q)$, is defined as:

$$p(q) = \frac{H(q)}{M \times N}. \tag{2}$$

The Cumulative Density Function $c(q)$ is given by:

$$c(q) = \sum_{i=X_0}^{q} p(i), \tag{3}$$

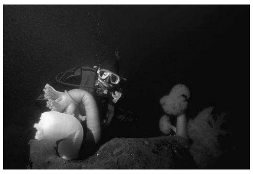
where X_0 is the smallest intensity within the range where we want to calculate the cumulative density function.

$$f(q) = X_0 + (X_{L-1} - X_0) \times c(q). \tag{4}$$

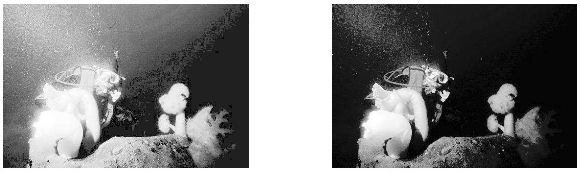
For our experiments we will use the modified equalization function $g(q)$ presented by Ibrahim et al., which improves the performance of the traditional equalization function [12], shown in Equation 4. The function is defined as:

$$g(q) = X_0 + (X_{L-1} - X_0) \times [c(q) - 0.5 \times p(q)], \tag{5}$$

where X_0 is the minimum intensity and X_{L-1} is the maximum intensity, within the range where the equalization function is calculated, $c(q)$ represents the function of cumulative density and $p(q)$ is the probability of occurrence, of the $q-th$ intensity. The following is a brief description of the technique that will help us solve the problems presented by the HE.



(a) Original image with low contrast.



(b) Equalized with HE. (c) Equalized with CHE.

Figure 1: Equalized Image with different methods

2.2 Clipped Histogram Equalization

As mentioned previously, the HE produces an over improvement in the image. This over improvement causes the image to lose quality and remain with an unnatural appearance. In Figure 1(a) it can be seen an image with low contrast that has not yet been equalized. In Figure 1(b) it is observed that the HE introduces saturation levels in the image equalized in comparison to the original image. This causes certain areas of interest to the observer to be degraded and can not be distinguished. On the other hand, in Figure 1(c) it can be seen how a CHE-based technique manages to mitigate HE problems. This technique manages to improve the contrast of the image and also preserves its average brightness. The following describes briefly what the CHE consists of.

The techniques that use *Clipped Histogram Equalization* (CHE) try to mitigate the problems caused by HE, mentioned in the introduction, limiting the improvement of contrast that is desired, in this way it is preserved the average brightness and a great loss of information in the image is avoided. As the histogram transformation is a function of $c(q)$, the improvement rate is directly proportional to the derivative of $c(q)$, given by [10]:

$$\frac{d}{dq}c(q) = p(q). \tag{6}$$

Therefore, if we want to limit the improvement rate, we should limit the value of $p(q)$, or directly $H(q)$ [13]. This trimming technique alters the shape of the histogram by reducing or increasing the values in the containers of the histogram based on a limit of cut, which consists in choosing a value threshold to limit the rate of improvement, before the equalization takes place. The trimmed portions must be redistributed back to the histogram, so as not to leave the histogram inconsistent [14].

We consider that the BPCLBHE method provides the most desirable qualities as a contrast enhancement method, since it is based on the preservation of the average brightness, and produces an improvement in contrast without degrading the quality of the image. In the following section, we present our extension to the method which segments the global histogram into four subhistograms, instead of two subhistograms.

3 Proposed Method

The idea of the new method of equalization is to divide the global histogram into four subhistograms, with this we intend to obtain the smallest possible difference in brightness between the input image and the output image. We will modify these subhistograms independently: first clipping the histograms at certain frequency, then homogeneously distributing the removed values along each subhistogram. Finally, the image is equalized with the mapping function of the cumulative modified histogram [13], obtained after joining the four modified subhistograms.

We initially calculate the expected average intensity SP of the global histogram of the image as:

$$SP = \sum_{q=0}^{L-1} p(q) \times q, \tag{7}$$

where $p(q)$ is the probability of occurrence of the $q-th$ intensity and L represents the maximum amount of gray levels in the image.

Then we separate the global histogram into two subhistograms on the intensity value SP, calculated using the equation (7). The global histogram is separated into two subhistograms: the subhistogram of the bottom H_L and the subhistogram of the top H_U, as illustrated in Figure 2. H_L contains the values of intensities found from the minimum level of gray in the image l_{MIN} up to the average intensity SP, while H_U contains the values of intensities found from from $SP+1$ to the maximum level of gray in the image l_{MAX}. l_{MIN} is the lowest effective intensity within the image, that is, the lowest intensity within the histogram that appears at least once in the image, so l_{MAX} represents the maximum effective intensity found in the image, that is, the greater intensity within the histogram that appears at least once in the image.

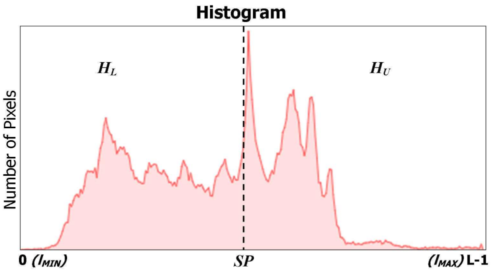


Figure 2: Global histogram after the first segmentation.

Finally, we calculate the average intensities expected for H_L and H_U, as SPL and SPU respectively, according to the equations:

$$SPL = \sum_{q=0}^{SP} p(q) \times q, \tag{8}$$

$$SPU = \sum_{q=SP+1}^{L-1} p(q) \times q. \tag{9}$$

These values serve to separate both subhistograms H_L and H_U in two subhistograms: H_{L1} and H_{L2} on intensity SPL, and H_{U1} and H_{U2} on intensity SPU respectively. Formally, the four subhistograms H_i, with $i \in \{L1, L2, U1, U2\}$ are defined as:

$$H_i = \{H(q) | \; q \in R_i\}, \tag{10}$$

where R_i is the range of intensities of each subinterval, in particular $R_{L1} = [0, SPL]$, $R_{L2} = [SPL+1, SP]$, $R_{U1} = [SP+1, SPU]$, and $R_{U2} = [SPU+1, 255]$, as illustrated in Figure 3. The image histogram of a grayscale image of $M \times N$ pixels can be seen as a monotonically non-decreasing sequence of $M \cdot N$ integers within the interval $[0, 255]$. As defined, the histogram segmentation limits $SPL < SP < SPU$ also belong to the same interval. Therefore, the sets of pixels that belong to the disjoint subintervals $[0, SPL]$, $[SPL+1, SP]$, $[SP+1, SPU]$ and $[SPU+1, 255]$ are also disjoint. Formally, the histogram sequence $\mathscr{H} = \{h_1, \ldots, h_{M \cdot N}\}$ satisfies that $h_i \leq h_{i+1} \forall i$. The average intensity in the sequence $\mathscr{H}$, SP (calculated in equation (7)) is such that $h_1 \leq SP \leq h_{M \cdot N}$, and assuming we work with an image with at least three different gray intensities, the relation satisfies: $h_1 < SP < h_{M \cdot N}$. Therefore, by the monotonicity of the sequence, an element $h_j \in \mathscr{H}$ exists such that: $h_j \leq SP \leq h_{j+1}$, and $h_j < h_{j+1}$, so the subsequences $\mathscr{H}_L = \{h_1, \ldots, h_j\}$ and $\mathscr{H}_U = \{h_{j+1}, \ldots, h_{M \cdot N}\}$ are disjoint, where $\mathscr{H}_L$ belongs to the interval $[0, SP]$ and $\mathscr{H}_U$ belongs to $[SP+1, 255]$. The

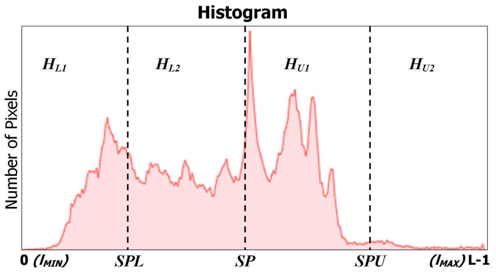


Figure 3: Global histogram after the second segmentation.

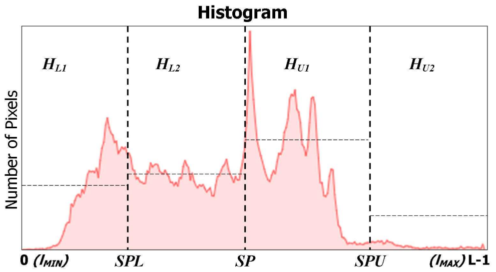


Figure 4: Global histogram with calculated cutoffs.

same argument is valid to prove that the subsequent division of the histogram into four intervals yields non-overlapping pixel partitions. Notice that this histogram segmentation does not adhere to a traditional image segmentation, and does not take into account spatial adjacency.

To control the over improvement and obtain a natural appearance, we use the trimming technique to modify the 4 subhistograms. Following the ideas from BPCLBHE, we find cut-off limits for each subhistogram, and then redistribute the excess pixels among the other intensities in the subhistogram. We can formally define the steps as:

Step 1: Calculate the cut-off limits CL_i (illustrated in Figure 4) as:

$$CL_i = \left\lceil \frac{N_i}{I_i} \right\rceil + round\left(\gamma \times \left(N_i - \frac{N_i}{I_i}\right)\right), \tag{11}$$

where $\lceil\rceil$ is the round-up function, $\gamma \in \mathbb{R}$ with $0 \leq \gamma \leq 1$ is a parameter to control the contrast, I_i is the length of each interval R_i, and N_i is the number of pixels within the subinterval H_i, calculated as:

$$N_i = \sum_{q \in R_i} H_i(q). \tag{12}$$

Step 2: Compute the total numbers of pixels that exceed the cutoff limit for each level of gray in each subhistogram T_i, as:

$$T_i = \sum_{q \in R_i} max(H_i(q) - CL_i, 0), \tag{13}$$

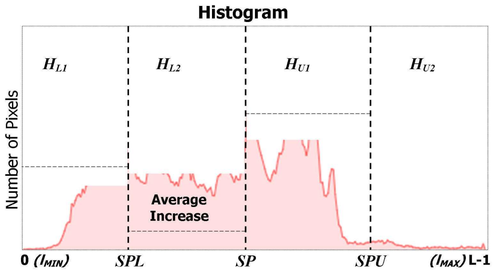


Figure 5: Histogram after the modifications made by the calculated limits.

Step 3: The average increment AI_i for each level of gray for the subhistogram H_i is calculated as:

$$AI_i = \left\lfloor \frac{T_i}{I_i} \right\rfloor, \tag{14}$$

where $\lfloor\,\rfloor$ is the round-down function.

Finally, we use the cutoff limit CL and the average increase AI to trim each subhistogram and redistribute the excess pixels in each gray level. The trimmed subhistograms H_i' are calculated as:

$$\text{H'}_i(q) = \begin{cases} CL_i & \text{if } H_i(q) > CL_i - AI_i \\ H_i(q) + AI_i & \text{otherwise} \end{cases} \quad \forall q \in R_i. \tag{15}$$

Figure 5 illustrates how the histogram remains after being trimmed. Finally, each subhistogram is equalized independently, according to the Equation 5, once the process of modifying the histogram has finished. In the following section, the experimental results are presented, making a comparative analysis between the existing methods in the literature and the proposed method.

4 Experimental Results

In this section a comparative analysis of the proposed QHELC method is presented with the following methods: HE, BBHE [4], DSIHE [6], MMBEBHE [7], BHEPL [5], BHEPL-D [8], BHE3PL [9], BHE2PL [10] and BPCLBHE [11]. To validate the effectiveness of the proposed method, the comparative analysis is done using 7 metrics.

The section is composed of two experiments: first, we systematically compare the image distortion throughout the ranges of contrast possible for our method and other smooth parametric methods; then we analyze the competitive advantages, such as execution time and performance, of QHELC and other state of the art methods.

The image dataset for all experiments contains 239 8-bit images, and was produced by Aquino-Morínigo *et al.* [10]

[1]. All the images in the dataset are of either 2248 × 4000 or 4000 × 2248 pixels, and were converted to grayscale for our experiments. All the algorithms were implemented with the framework of Java ImageJ version 1.48 and were executed in a personal computer with Intel Core i3-M350 2.27 GHz, 4 GB of RAM and Windows 10 Home-64bits Operating System.

4.1 Experiment 1: Sensitivity analysis of the contrast

From the presented methods, both QHELC and BPCLBHE can produce different levels of contrast by varying their contrast enhancement parameter γ. We can evaluate the distortion after the contrast enhancement through the change in brightness [15], and how the distortion behaves as the contrast improves.

The contrast [9] measures the difference in luminance or color that makes an object distinguishable within an image. In the following tests, we will consider the average contrast of all images in the dataset (dataset contrast for short) as the comparison parameter between different methods.

We compare the performance of the methods through the following measures:

- The Absolute Mean Brightness Error (AMBE) [15]: This metric measures the performance in the preservation of the original brightness. The lower the AMBE value, the better the preservation of the brightness of the image.
- The Contrast/Original Contrast Ratio (CR): This metric measures whether the initial contrast of an image is improved. If the value is greater than 1, then the image obtained an increase in contrast.
- The AMBE to Contrast/Original Ratio (A/CR): This metric quantifies the distortion of the average brightness needed for a given improvement in contrast. The lower the value, the better the preservation of the average brightness.
- The Contrast Improvement Ratio (CIR) [19]: This metric measures the improvement of the local contrast in the image. The higher the better.
- The Lightness Order Error (LOE) [20]: This metric is used to objectively measure the lightness distortion of enhanced results. The lower the better.

As γ varies from 0 to 1, the both methods tend to improve the dataset contrast, however the improvement is not necessarily smooth. Therefore we obtain dataset contrast values which differ less than 1 to make QHELC and BPCLBHE comparable, and tally the results in Table 1 and Table 2. Both methods naturally produce different ranges of contrast, and they can be directly compared within the overlap. QHELC outperforms BPCLBHE throughout all the comparable database contrast range, and produces a lower AMBE, and A/CR. A/CR indicates that BPCLBHE tends to add proportionally more image disturbance. Furthermore, QHELC can produce results for smaller contrast improvements than BPCLBHE, between 55.59 and 58.21, which incur in even smaller AMBE rendering very well preserved images. Although BPCLBHE can produce contrast values higher than QHELC, the proposed method obtains a higher ratio of local contrast improvement while its lightness distortion values keep lower than BPCLBHE, making the images present a more natural aspect.

Table 1: Averages of Contrast (C), AMBE (A), CR and A/CR

QHELC					BPCLBHE				
γ	C	A	CR	A/CR	γ	C	A	CR	A/CR
0	55.59	0.61	1.04	0.59	-	-	-	-	-
0.001	56.16	0.81	1.05	0.77	-	-	-	-	-
0.003	57.21	1.24	1.07	1.16	-	-	-	-	-
0.004	57.69	1.44	1.08	1.33	0	58.21	2.29	1.09	2.1
0.008	59.27	2.16	1.11	1.95	0.0005	59.09	2.74	1.10	2.49
0.01	59.90	2.45	1.12	2.19	0.001	59.89	3.21	1.12	2.87
0.015	61.15	3.03	1.14	2.66	0.002	61.35	4.10	1.14	3.6
0.020	62.03	3.43	1.16	2.96	0.0025	61.99	4.51	1.16	3.89
0.030	63.12	3.95	1.18	3.35	0.003	62.59	4.90	1.17	4.19
0.055	64.20	4.50	1.20	3.75	0.004	63.66	5.64	1.19	4.74
1	64.84	5.19	1.21	4.29	0.0055	65.05	6.62	1.21	5.47
-	-	-	-	-	0.007	66.19	7.43	1.24	5.99
-	-	-	-	-	1	72.11	13.89	1.35	10.29

Table 2: Averages of CIR and LOE

QHELC				BPCLBHE			
γ	C	CIR	LOE	γ	C	CIR	LOE
0	55.59	0.20	48.26	-	-	-	-
0.001	56.16	0.25	52.35	-	-	-	-
0.003	57.21	0.41	61.00	-	-	-	-
0.004	57.69	0.52	62.64	0	58.21	0.24	64.11
0.008	59.27	1.08	64.52	0.0005	59.09	0.32	66.48
0.01	59.90	1.42	65.24	0.001	59.89	0.40	68.81
0.015	61.15	2.16	65.62	0.002	61.35	0.61	71.21
0.020	62.03	2.89	66.64	0.0025	61.99	0.74	71.94
0.030	63.12	3.85	67.52	0.003	62.59	0.87	72.18
0.055	64.20	6.46	68.63	0.004	63.66	1.11	73.52
1	64.84	12.61	71.08	0.0055	65.05	1.53	74.29
-	-	-	-	0.007	66.19	1.94	74.80
-	-	-	-	1	72.11	16.52	77.99

The γ parameter determines a value for the cutoff limit. This limit can vary between the average frequency of the subhistogram and the maximum possible peak of the subhistogram, since the idea of the cutoff is to redistribute the pixels that exceed it in the subhistogram. Therefore, it would not make sense that the limit is less than the average frequency per intensity of the subhistogram, then the γ value must be greater than or equal to 0. On the other

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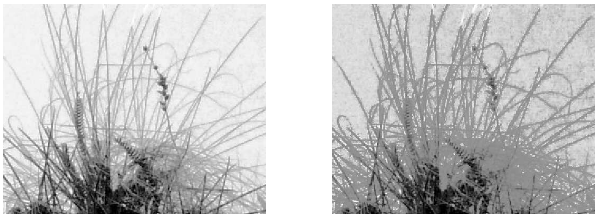
[1] Images can be requested from the authors in the e-mails indicated in this work.

hand, the maximum value of γ is 1, because a cut-off limit higher than the total number of pixels of the subhistogram would not fulfill the function of trimming the subhistogram, even in the extreme case in which all the pixels of the subhistogram have the same intensity. Then, the larger the γ, the higher the cut-off limit and the fewer pixels of the subhistogram are redistributed, causing a greater stretch of the contrast to be applied when the equalization is applied to the subhistogram. On the other hand, the lower the γ, the lower the cutoff and the more pixels are redistributed in the subhistogram, resulting in a lower contrast improvement when applying the equalization to the subhistogram.

Figure 6 shows an example excerpt of image 82 in the database, equalized with BPCLBHE and QHELC. Subfigures (b) and (c) show the image at the smallest contrast for BPCLBHE ($\gamma = 0$) with the comparable QHELC ($\gamma = 0.004$), we can see that BPCLBHE starts to blend the light colored leaves with the background (which can be appreciated in the change in volume), while QHELC preserves the aspect better. The distortion becomes more apparent using the highest contrast for both methods ($\gamma = 1$). Our method shows a good performance keeping the natural aspect from the original image even when the distortion is maximum.

(a) Original

(b) QHELC with γ=0.004 (c) BPCLBHE with γ=0



(d) QHELC with γ=1 (e) BPCLBHE with γ=1

Figure 6: Excerpt of Image 82 from the database and the respective equalizations.

4.2 Experiment 2: Comparison between our proposal and state-of-the-art methods

This experiment intends to analyze many characteristics of QHELC and the main methods presented in the literature. In addition to AMBE, CIR and LOE, the following metrics were evaluated:

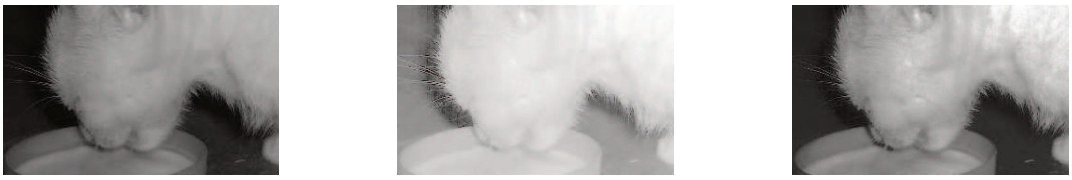
1. The execution time: This metric quantifies the time required to process a single image by the algorithm (measured in milliseconds).
2. The *Peak Signal to Noise Ratio* (PSNR) [16]: This metric quantifies the amount of noise introduced in the image after having been processed. The PSNR is measured in decibels, and the higher the value, the lower the noise introduced in the transformation of the image and therefore the quality of the output image is better.
3. Entropy [9]: This metric quantifies the richness or quantity of details in the processed image. The greater the entropy, the greater the amount of detail information in the image.

Table 3: Results averaged for the images collected in[10]

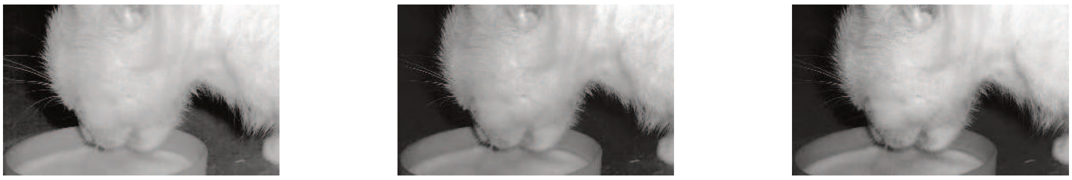
Methods	T(ms)	AMBE	PSNR	Entr.	Cont.	CIR	LOE
Original				6.887	53.591		
HE	**97.585**	37.245	14.659	6.688	**73.552**	**19.273**	77.835
BBHE	**95.343**	13.763	19.159	6.718	**72.424**	**18.873**	78.061
DSIHE	102.826	15.952	18.145	6.718	**75.573**	**19.542**	80.553
MMBEBHE	100.675	2.853	22.449	6.703	64.210	16.062	78.554
BHEPL	**99.888**	9.026	22.761	6.813	69.135	6.585	69.058
BHEPL-D	100.808	7.654	26.276	6.717	63.094	7.601	346.524
BHE3PL	101.161	**1.265**	**40.321**	**6.828**	55.145	0.089	**32.719**
BHE2PL	101.258	**0.763**	**44.273**	**6.828**	54.440	0.070	**26.996**
BPCLBHE	111.364	2.287	32.932	**6.864**	58.213	0.245	64.105
QHELC	123.649	**0.612**	**38.934**	**6.858**	55.594	0.199	**48.256**

Table 3 shows in bold the 3 most competitive results for each metric. BPCLBHE and QHELC were run with $\gamma = 0$, as both methods get their best AMBE results with this configuration. The execution time (second column) is an average of 10 runs of the entire database. QHELC has the best result in the AMBE metric, even considering the lower contrast and CIR values from the BHE3PL and BHE2PL methods. Although QHELC has a longer execution time, it has the second best Entropy, the third best PSNR and the third best LOE among the evaluated methods.

Figure 8 shows an extended comparison of AMBE versus Contrast for all methods (except for HE, that was excluded for better visualization), which integrates data from Table 1 and Table 3. In this figure points to the lower right indicate a better performance. We can consider the contrast and AMBE improvement as a multi-objective problem [17], improving contrast usually conveys

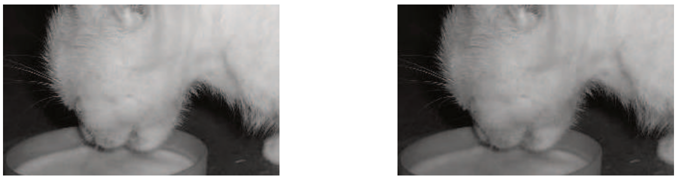


(a) Original (b) HE (c) BBHE



(d) DSIHE (e) MMBEBHE (f) BHEPL

(g) BHEPL-D (h) BHE3PL (i) BHE2PL



(j) BPCLBHE (k) QHELC

Figure 7: Excerpt of an image taken from the database collected in [10] with their respective equalizations.

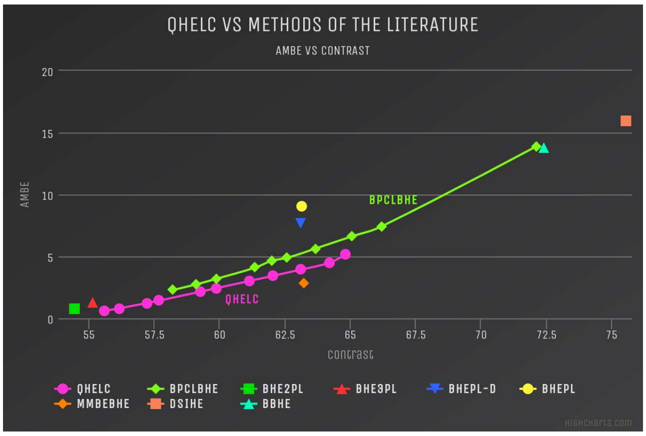
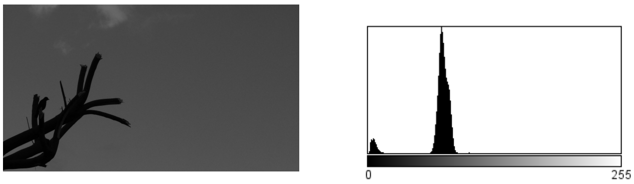


Figure 8: AMBE vs Contrast

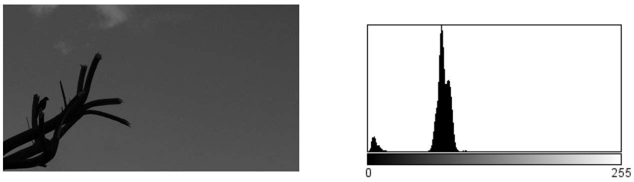
a decrease on image quality (i.e. higher AMBE). Under this consideration, each point dominates all points located above and to the left in the figure. Our method (pink) is only dominated by MMBEBHE (orange diamond) on a limited subset of results (database contrast 62 to 63 approximately), and dominates all other comparable methods throughout its domain (database contrasts 55 to 65).

Figure 7 is a snippet of a picture with a light foreground (a white kitten) clearly visible on top of a dark background with occluded features. Figure 7(b) shows how HE over improves the foreground contrast, rendering many features indistinguishable. Figures 7(c), (d), (e), (f) and (g), introduce less brightness than HE, but still introduce excessive brightness and give the fur an unnatural appearance. Figures 7(h),(i) and (j) do not distort the image, however they just lighten the foreground without much contrast improvement. Finally, Figure 7(k), that corresponds to QHELC, improves the contrast of the original image, making details more prominent without introducing an excess in brightness, which keeps the image with a natural appearance.

QHELC did not improve the initial contrast of 3 images out of 239 (1% of the total). We noticed that in the images there is a big portion of background and some continuous dark objects, also the respective histograms have at least one peak (almost in the middle). In Figure 9 we can see example images (original and processed) with their respective histograms.



(a) Original image (b) Histogram of original image



(c) Processed image by QHELC (d) Histogram of processed image

Figure 9: Case of failure

5 Conclusions and Future Work

In this work we present a novel equalization method based on the preservation of the average brightness, called Quadri-histogram Equalization with Limited Contrast (QHELC). The method uses two techniques: histogram segmentation, and clipping. Initially, the average brightness of the image is considered as the threshold to segment the global histogram of the image in 4 subhistograms, which leads to preserving the brightness. Then, the histogram is clipped, which leads to maximize the entropy, and to control the improvement rate that we want to apply. The experiments show that there is a strong correlation between Contrast and AMBE: the lower the Contrast achieved, the lower the AMBE obtained. Notwithstanding QHELC produces better AMBE, CIR and LOE values than BPCLBHE for all their comparable results, and dominates most comparable methods according to that method. Finally, the experimental results indicate that the proposed method is also competitive considering PSNR and Entropy. The method also presents a reasonable execution time with respect to the classical methods. As future work, QHELC could also be applied to grayscale aerial thermal images, since they need to be enhanced in terms of contrast and details for many applications [18].

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