Evaluation of GIMP Retinex Filtering of Images by Means of the Shen++ Max Shannon Entropy Finder

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Abstract: Retinex filters are used for processing and enhancing images, obtaining very good results when the images have a degraded contrast, such as those recording foggy or nighttime scenes. Among the several existing Retinex filters, one freely available on the web is that provided by GIMP, the GNU Image Manipulation Program. This software has some parameters that can be adjusted to optimize the output image. Here we investigate a criterion for the optimization of filtering parameters, based on the maximization of image entropy, evaluated using the Shannon formalism. For this task a software, the *Shen++ Max Shannon Entropy Finder*, is proposed. The software is working on a bulk set of images generated after processing the original image with several different values of the filtering parameters, giving the filtered images having the largest and the smallest Shannon entropy.

Keywords: Image Processing, Foggy Images, Nighttime Images, Retinex, Shannon Entropy, Generalized Entropies.

Introduction

In recent papers [1,2], we have proposed and discussed the use of the Retinex filter of GIMP, the GNU Image manipulation Program, for enhancing images coming from radiographic devices and from microscopes. In general, a Retinex filter can be used for processing and enhancing images, obtaining very good results when they have a degraded contrast, such as the images recording foggy or nighttime scenes. The fact that a Retinex filters is suitable for processing such images is based on its ability of simulating the human vision. Humans are able of seeing details both in the shadows and in the nearby illuminated areas, whereas a photograph or a digital image of the same observed scene are showing either the shadows as too dark or the bright areas as overexposed [3]. The fundamental reason of such discrepancies is that human vision has some specific features concerning colours, brightness and contrast of a scene that are quite different from those of recording devices [4].
Inspired by the human vision biological mechanism to adapt itself to these conditions, Edwin H. Land, an American scientist and inventor, best known as co-founder of Polaroid Corporation [5-9], devised and proposed the first Retinex method of processing images. Through his research works, Land evolved his model until the last version proposed in 1986. The term “retinex” was coined by Land himself combining the words “retina” and “cortex”, and used to indicate the results of his researches, which were showing that the human colour perception is involving all levels of vision processes, from the retina to the cerebral cortex. After the first method proposed by Land, several other Retinex approaches had been developed [4-10]: the single-scale Retinex (SSR), the multiscale Retinex (MSR), and, for colour images, the MultiScale Retinex with Colour Restoration (MSRCR). GIMP Retinex is a freely available tool of this last family, developed by Fabien Pelisson [11].

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Due to the specific features of the Retinex filtering, this filter seems very effective in enhancing the images concerning foggy and nighttime scenarios [12-19].
In a Retinex filtering of images, such as in the GIMP Retinex filtering, the resulting image can be adjusted selecting different parameters and then, to each set of parameters an output image is corresponding, having a different visual rendering. Of course, we can decide to adjust the image in consequence of a qualitative approach based on our personal view; however, if our aim is that of having an automatic choice of the best output image, a decision method based on a quantitative evaluation of the filtering is necessary. Since each image is composed of colour tone having in it a specific frequency, if we apply to any image a filtering, we have consequently that the filtered image possesses a different distribution of frequencies of colour tones. Here we use a quantitative method based on the Shannon entropy. A software, *Shen++ Max Shannon Entropy Finder*, is also proposed; this software, working on a bulk set of images generated after processing the original image with several different values of filtering parameters, is giving a filtered image having the maximum (and the minimum) of Shannon entropy.

Image entropy

In 1948, Claude Shannon defined the entropy H of a discrete random variable X, as the expected value of its information content, that is, $H(X) = \sum_i p(x_i) I(x_i) = -\sum_i p(x_i) \log_b p(x_i)$ [20,21]. In this expression, I is the information content of X, the probability of i-event is p_i and b is the base of the used logarithm (common values are 2 or Euler's number e). Therefore, the entropy is a measure of the information contained in a sample set of possible events.
If we consider an image and its grey tones, we can calculate an entropy by using the histogram of the tones, instead of the probability distribution. In this manner, we have the "image entropy". In the calculus of image entropy, the Shannon entropy can be used but also the generalized entropies of Tsallis and Kaniadakis [22-27]. In the Appendix, definitions and relations between these entropies are shortly discussed for reader convenience.
Since each image has its entropy, when we apply a filtering on it, its histogram is modified and consequently the entropy is changed. If the filtering has some adjustable parameters, we have the possibility of optimizing them, according to a suitable best choice. In [13] for instance, we proposed for the GIMP Retinex a ranking of output images, based on the local variance of grey tones. Here, we simply consider the use of the entropy; in this approach, the best choice of parameters is that corresponding to a filtered output image, which is maximizing entropy.
The GIMP Retinex is Multi-Scale Retinex with Colour Restoration (MSRCR) [10], which is a freely available tool developed by Fabien Pelisson [11]. The output image of GIMP-Retinex can be adjusted selecting different levels, scales and dynamics. We have three "levels" of filtering. The uniform level is treating both low and high intensity areas in the same manner. The low level enhances the lower intensity areas of the image whereas the high level is favouring the clearer areas. Another parameter of the filter is the "scale", which determines the depth of the Retinex scale. A "scale division" determines the number of iterations in the multiscale Retinex filter. The last parameter is a "dynamic" slider, which allows adjusting color saturation contamination around the new average color. The default values of scale, scale division and dynamic slider are 240, 3 and 1,2 respectively. In the Figure 1 we are showing an example of the use of GIMP Retinex on an image having pixels with grey tones. It is a showing a foggy street. The original image is given in the left-upper panel; the other images had been obtained using GIMP Retinex at uniform, low and high levels. The best level seems to be that obtained using the low level.

Let us stress that GIMP Retinex, like any Retinex filter had been developed for being used on images having colour tones. An example is proposed in the Figure 2, where we observe a nighttime scene. The original image is given in the left-upper panel, and, as in the case of the Figure 1, the other images are the outputs of GIMP Retinex filtering at uniform, low and high levels.

Evaluating entropy with the *Shen++ Max Shannon Entropy Finder*

Let us consider a grey tone image and calculate the Shannon entropy image and the Kaniadakis entropy, in the range of its entropic parameter [0,0.1] (see the appendix for formulas). The Shannon entropy is the limit value of Kaniadakis entropy when the entropic index approaches zero. Let us start from four images given in the Figure 1. We can see the original image and the three images obtained after filtering with GIMP Retinex setting the default values, in the case of the three levels, uniform, low and high. Looking at Figure 1 it seems that it is the low level the possible best choice, and in fact, as we can see in the plot of Figure 3, the image obtained with the filter at low level has the highest value of entropy.

Of course, besides the choice of level, we have also to determine the values of the other three parameters. Let us consider the dynamic slider for instance. In the Figure 4, we have four images obtained from filtering in low level, with the default values of scale and scale division, but having different values of dynamic slider. In this case, the choice of the best image is not so evident. If we consider their entropies, we have the results given in the Figure 4. In this figure, it is also plotted the entropy of the original image as reference. Note that, in this case, two of the filtered image are worse than the original. Figures 3 and 4 are showing the entropy based on the grey tones of the image.

These examples and other given in [28] are showing that the entropy is sensitive in distinguishing the role of parameters. However, these examples are also telling that, when we decide to adjust all the parameters, it is necessary a calculation of the entropy on a bulk set of images, such as that considered in [13]. For the approach described in [13], we developed a simple script in Script-Fu, including loops used to generate the bulk set of images processed with GIMP Retinex, with all different values of its input parameters (s,n,d,l) in their range Ω. Parameters s, n, d and l, are the scale, scale division, dynamics and level parameters respectively.

To evaluate the images having the largest or the lowest entropies in a bulk set we have developed the *Shen++ Max Shannon Entropy Finder,* a software implemented in Visual Basic. The software is working on the histogram of equivalent colour tones, that is (R+G+B)/3, where R,G and B are the colour tones of pixels. In the Figure 5 we can see the snapshots of the software in two cases, when it is evaluating the entropy of a single image (maximum and minimum of entropy are coincident), and when it is working on the bulk set of images generated with GIMP Retinex. The values of the corresponding parameters are encoded in the name of the output image.

Discussion

The criterion of considering the image having the maximum entropy as the best output of the GIMP Retinex filtering, was preliminary proposed in Ref.28, and discussed there with an analysis of a few images. Here, using the *Shen++ Max Shannon Entropy Finder* , we had the possibility to work on a large set of images. As a result we have observed that, in the examined cases from which we have proposed the examples given in the Figures 5-7, the output having the maximum of entropy is giving also a good visual effect. It happens, in these cases, that the entropy of the selected Retinex filtered image is about 25% larger than the entropy of the original image.

This percentage value could seem small. However we have to consider that the Shannon entropy of any image is limited by a precise value. Let us consider the entropy in the case of a discrete distribution of probability which is uniform. It is immediate to see that, if we have *N* values, the entropy is equal to $H = -\sum_{i=1}^{N} (1/N)\ln(1/N) = -\ln(1/N) = \ln N$.

If *N* is the number of the colour tones, *N*=255, the entropy in the case of an uniform distribution of colour tones is equal to 5.54. The entropy of the uniform distribution is also the largest entropy we can find from an image. Then, since the entropy of the original image is quite large, the entropy of the GIMP Retinex processed image can increase of a relatively small amount.

However, there are also cases for which a large variation of entropy is observed. An example is given in the Figure 8. The case proposed in this figure has the original image with a histogram possessing two peaks at black and white tones. The entropy of the original image is 1.09, then quite smaller of the limit value of entropy, 5.54. In the bulk set of the filtered images we find a maximum entropy of 4.68. This entropy is more than four times the entropy of the original image. The large increase of entropy is produced by the GIMP Retinex which is introducing several other colour tones in the black and white regions. The output image corresponding the maximum of entropy, given in the Fig.8, has new colour tones and a histogram which has increased its richness and consequently the entropy. In this manner, from the simple example of Fig.8, we can see that a Retinex software can highlight the information contained in the image, by adding new color tones in the local environment.

In fact, after our analysis with the *Shen++ Max Shannon Entropy Finder*, we can agree to the conclusion of [29] about entropy: "although entropy does not directly represent the enhancement of image quality, it can depict the richness of details. In addition, when average and root mean square contrast do not change, entropy is a useful factor to understand the local or global contrast variation in the given image". In fact, we are working for preparing a new version of the software which is also considering other statistical parameters, such as average intensity and contrast, for investigating other features of the GIMP Retinex filtering of images.

Appendix

In the following formulas, we can see how the entropies of Shannon, Tsallis and Kaniadakis are defined. Tsallis and Kaniadakis entropies are generalized entropies depending on and entropic index. To apply these formulas to images, we have to consider p_i as the frequency of grey tones. The index I is giving the specific grey tone. We have:

$$\text{(A1)} \quad \text{Shannon}: \ S = -\sum_i p_i \ln p_i$$

$$\text{(A2)} \quad \text{Tsallis}: T = T_q = \frac{1}{q-1}\left(1 - \sum_i p_i^q\right)$$

$$\text{(A3)} \quad \text{Kaniadakis}(\kappa\text{-entropy}): \ K_\kappa = -\sum_i \frac{p_i^{1+\kappa} - p_i^{1-\kappa}}{2\kappa}$$

In (2A),(A3) we have entropic indices q and κ. Note that $\lim_{q \to 1} T = S$; $\lim_{\kappa \to 0} K = S$.

If we have two independent subsystems A,B, the joint entropies H(A,B) are given by:

$$(A4)\quad S(A, B) = S(A) + S(B)$$

$$(A5)\quad T(A, B) = T(A) + T(B) + (1 - q)T(A)T(B)$$

$$(A6)\quad K(A,B) = K(A)\Im(B) + K(B)\Im(A) \quad \text{with } \Im = \sum_i \frac{p_i^{1+\kappa} + p_i^{1-\kappa}}{2}$$

Note that for the generalized additivity of κ-entropy, we need another function containing probabilities (see [26] and references therein). When we have a small value of the entropic index, function $\Im$ is equal to 1. For relations existing between Kaniadakis and Tsallis entropies, see please Ref.27.

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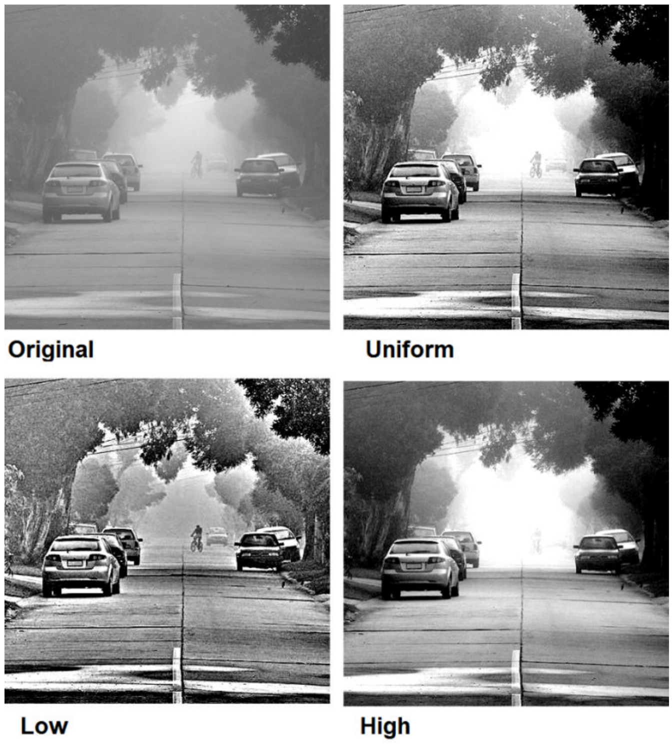

Figure 1: The original image is given in the left-upper panel, (Courtesy: Ian W. Fleggen, Wikipedia, 20880313, Foggy Street). The other images had been obtained using GIMP Retinex at uniform, low and high levels. The best level seems to be the low one.

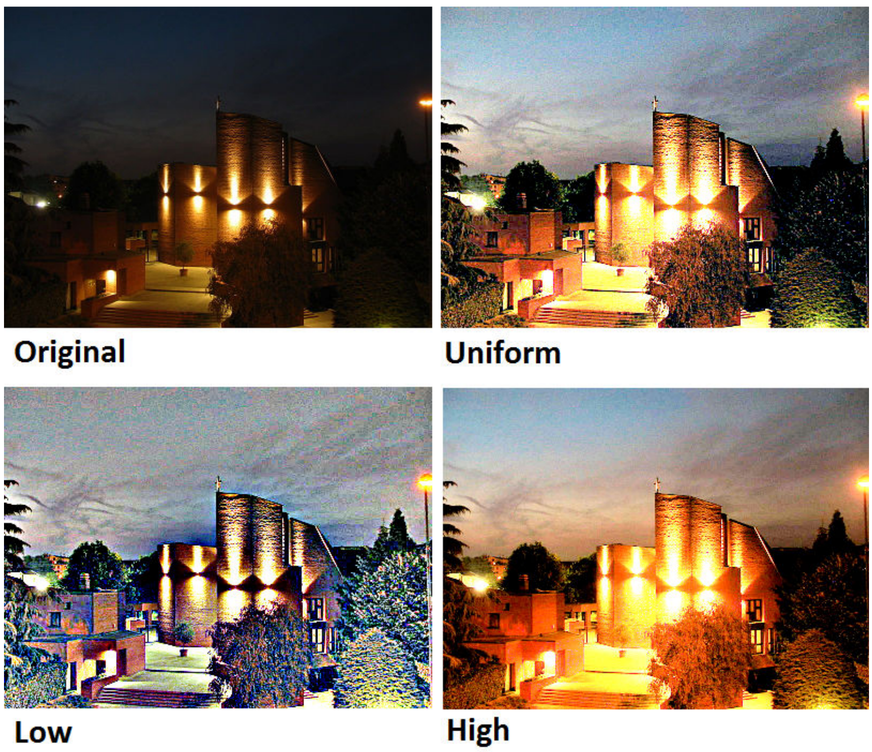

Figure 2: The original image is given in the left-upper panel, (Courtesy: Melari, Wikipedia, Curchby night in Monza). The other images had been obtained using GIMP Retinex at uniform, low and high levels. As in the Figure 1, the best level seems to be the low one.

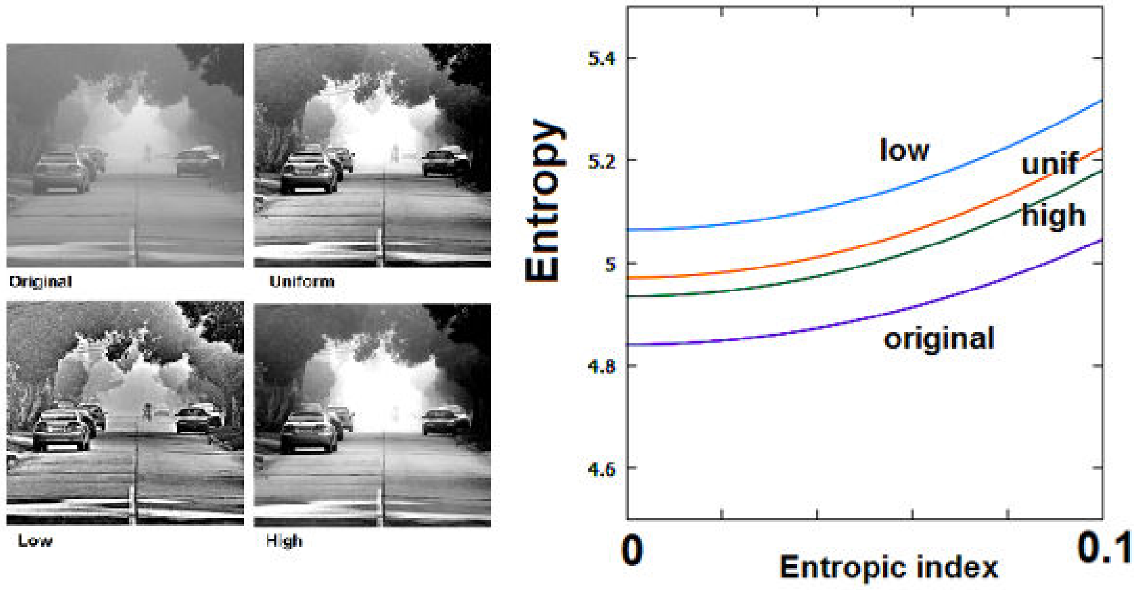

Figure 3: Of the images given in Fig.1, we can calculate the entropies. The plot shows the Kaniadakis entropy as a function of its entropic index. When this index approaches zero, Kaniadakis entropy becomes the Shannon entropy. The entropy is maximized in the case of the low-level filtered image.

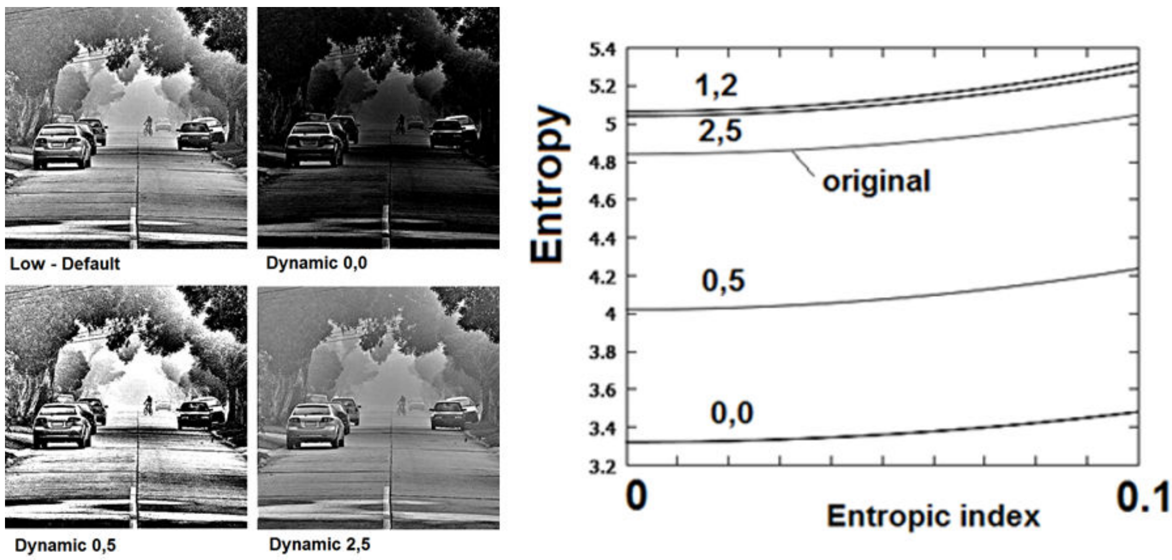

Figure 4: Considering low-level filtered images, we can adjust the value of the dynamic slider. The default value is 1,2. In the panel on the right, we can find the image entropies of the four images on the left.

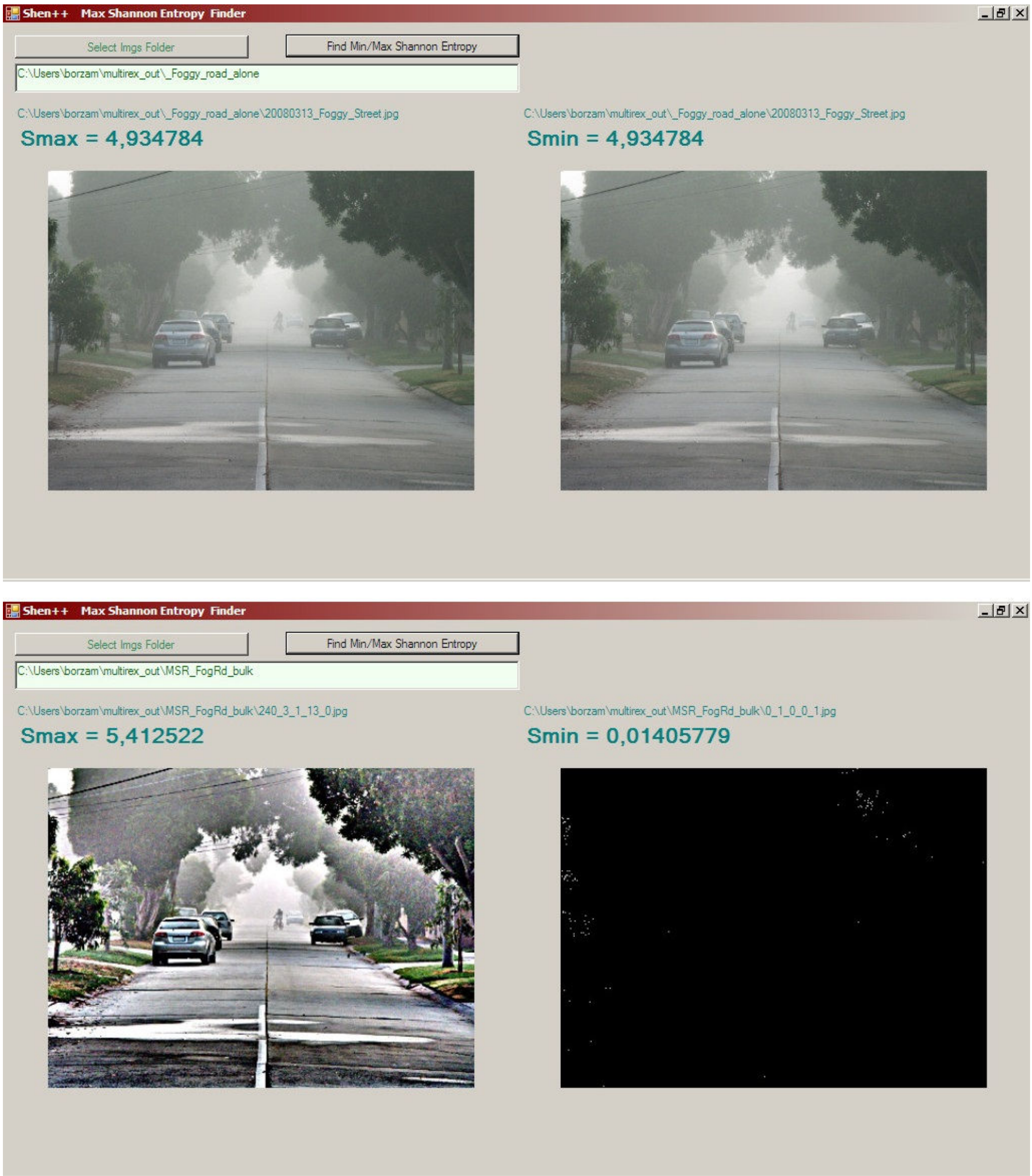

Figure 5: To find the images having the largest and the smallest entropy in a bulk set we have developed the *Shen++ Max Shannon Entropy Finder*, working on the histogram of the equivalent colour tones. Here we can see the snapshots of two cases. In the upper part, we see the evaluation of entropy on the single, original colour image, from which the grey tone image of Figure 1 had been obtained. Note that, since we have just one image, the maximum and minimum of entropy are coincident. In the lower part, we can see the images having the maximum and minimum of entropy from the bulk set of images generated with GIMP Retinex. The values of the corresponding parameters are encoded in the name of the output image.

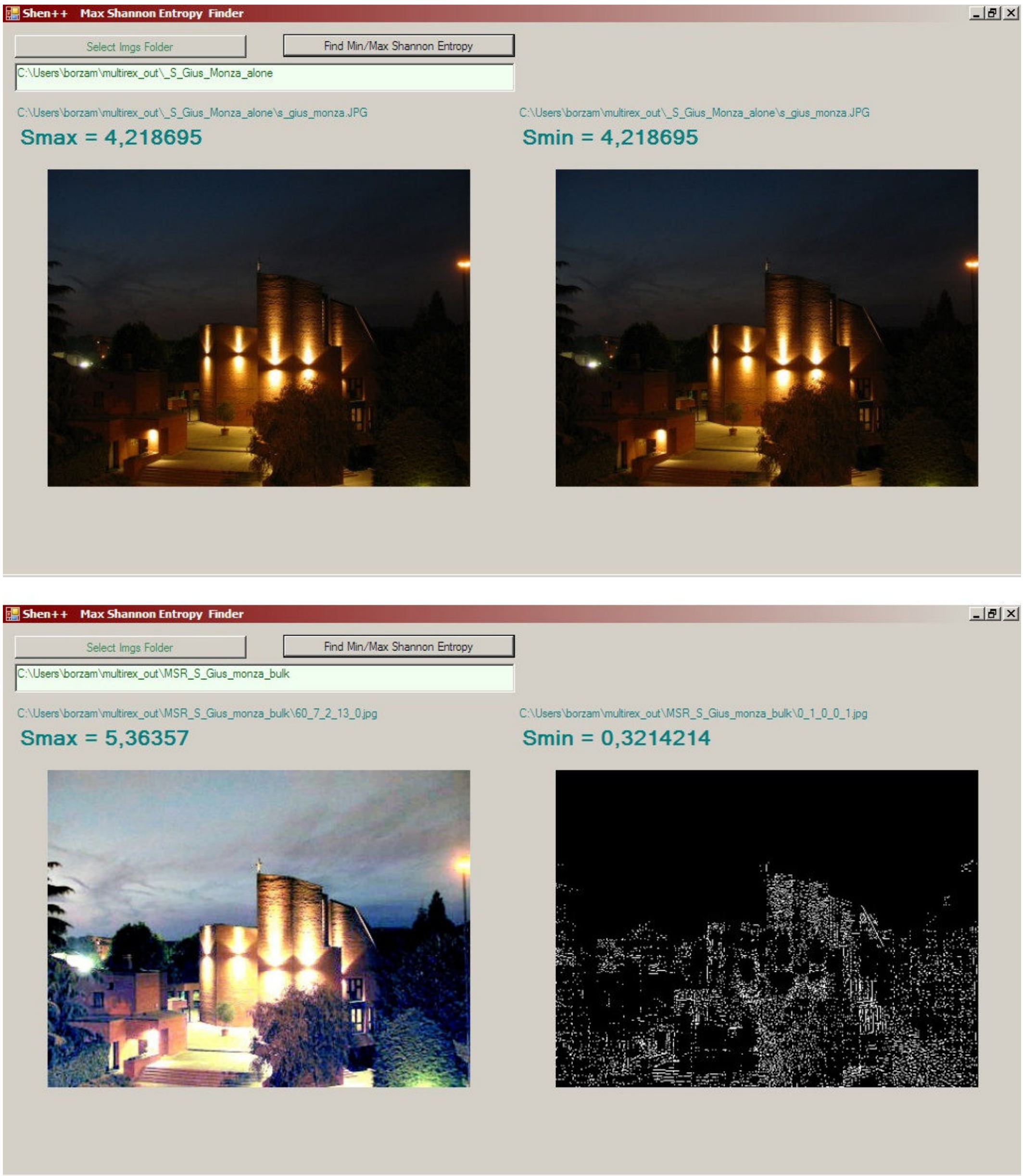

Figure 6: Two snapshots *Shen++ Max Shannon Entropy Finder*. In the upper part, we see the evaluation of entropy on the single, original image of Figure 2. In the lower part, we can see the images having the maximum and minimum of entropy from the bulk set of images generated with GIMP Retinex.

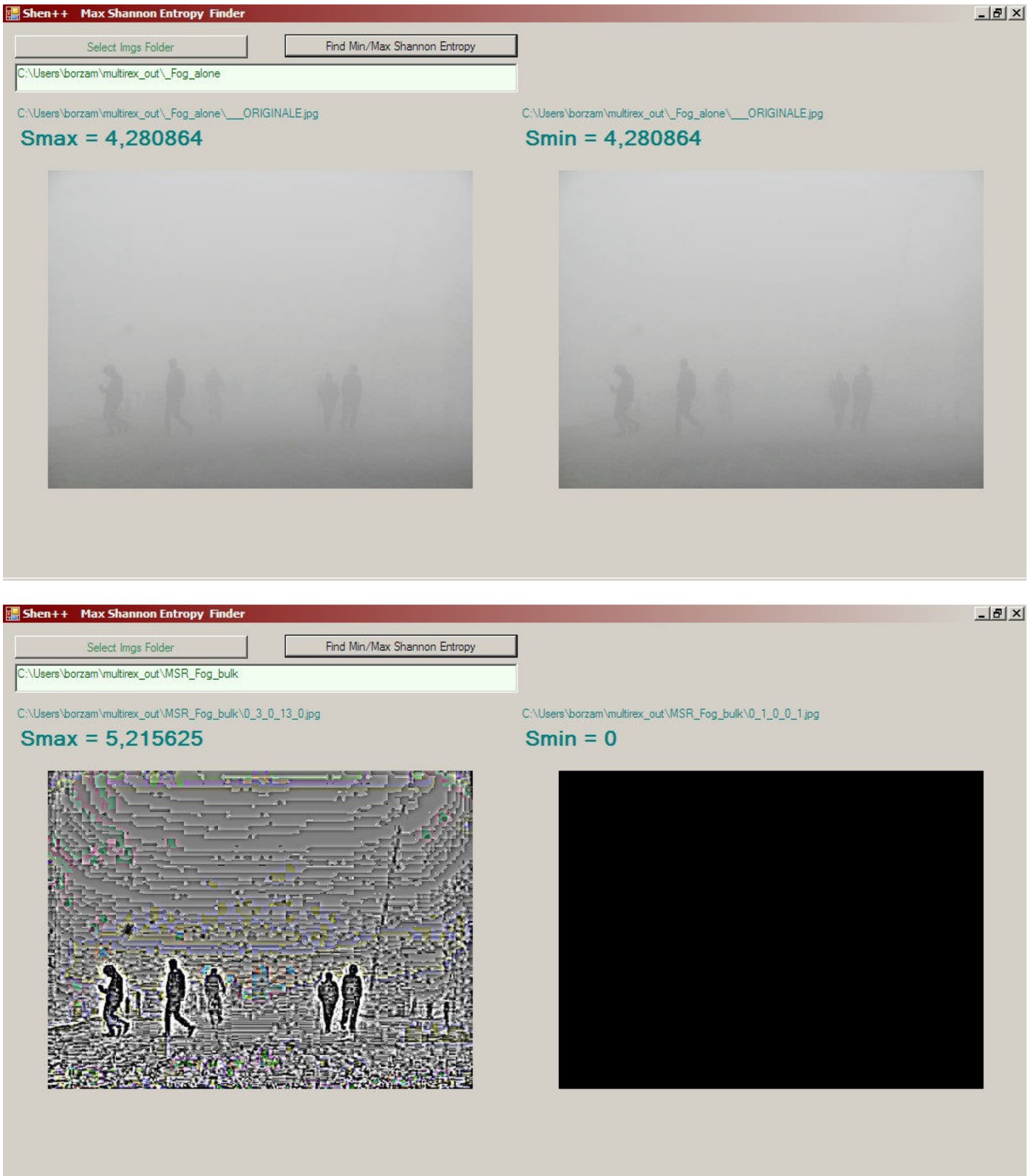

Figure 7: Two snapshots *Shen++ Max Shannon Entropy Finder*. In the upper part, we see the evaluation of entropy on the single, original image used for Ref. 13. In the lower part, we can see the images having the maximum and minimum of entropy from the bulk set of images generated with GIMP Retinex.

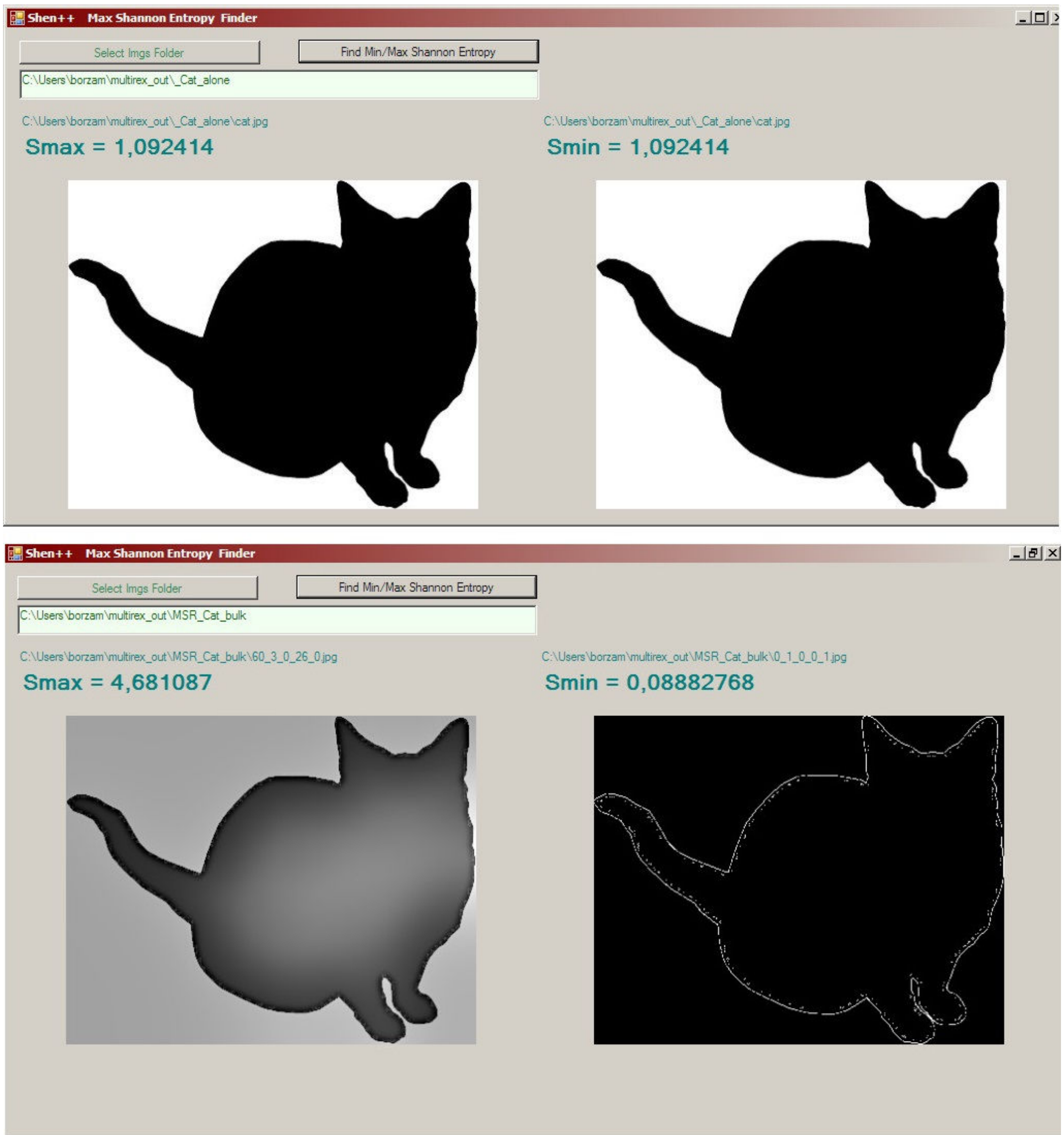

Figure 8: Two snapshots of the *Shen++ Max Shannon Entropy Finder*. In the upper part, we can see that the entropy of the black and white original image is 1.09 . In the lower part, we can see the images having the maximum and minimum of entropy. The large entropy (4.68) of the output image is obtained because GIMP Retinex software, for the given parameters corresponding to the output image, is adding several colour tones that are enriching the histogram.