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Enhancing Color Photographic Images by the Modified Power Law (MPL)

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Abstract --- **A new range of power variable based on the power law is introduced to enhance low contrast color photographic images. This variable, at the same time, removes noise appeared from truncation Y, Cb, Cr coefficients in the linear transformation of color spaces RGB into YCbCr . This new interval allows a gradual return of details hidden in a low contrast image, which details are often drowned in black who appeared on silver images due to a bad photo shooting. The study compares results obtained with the traditional power law (PL) and the modified power law (MPL) suggested. Results obtained show that the MPL is very effective in terms of progressive and finer revelation of hidden details present on image to be improved. Also, for a clear improvement of low contrast images, we don't need to normalize the grayscales.**

Keywords--- ***enhancing image, power law, modified power law, truncation noise, RGB → YCbCr and YCbCr → RGB transformations.***

I. INTRODUCTION

Many compression standards [1] of multimedia data (still or animated images) in particular JPEG, MPEG1, 2, 4 and H.261 use the space color transformation RGB → YCbCr and YCbCr → RGB (see appendix). The use of YCbCr color space optimizes compression [2] by reduction of chrominance data. However, this transformation induced on certain color photographic images an impulsive noise which appears in the form of green dots. This noise comes from truncation of Y, Cb, Cr coefficients, made during the storage of the transformed grayscales [9]. This truncation noise coexists with other noises like black caused by a lack of light during photo shooting.

In black Africa, many young unemployed try to overcome the economic difficulties by engaging in popular leisure photography. They are often present during events such as wedding ceremonies, training seminars, doctoral thesis, and dances. Lack of mastery in photographic shooting techniques often leads to degraded images by the appearance of very low contrast areas on them (see Figure 1a, 1b). This kind of images are very sensitive to truncation noise appeared during the y, cb, cr to r, g b coefficients transformation.

The paper is organized as follows. In Section 2 we highlight sensitivity to truncation noise of some low contrast photographic images compared with a normal contrast like Lena image. A comparative study is done in Section 3, concerning two enhancing techniques of image which are able to suppress the two above mentioned noises. These techniques are: the power law (PL) [3] and the modified power law (MPL) which we suggest. Indeed author [4] specifies normalization of the grayscales before applying PL technique. In Section 4 is described the experiment. Results and analysis are presented in Section 5, before concluding.

Some objective quality metrics like Signal Noise Ratio SNR to evaluate the quality of treated images, Mean Square Error MSE, mean M of grayscales [5], [6] are presented in the appendix.

II. THE POWER LAW (PL) AND THE MODIFIED POWER LAW (MPL)

2.1 The power law PL

Power law is a transformation that can change the contrast of an image within the dynamic range of display system [3]. It is given by equation (1).

$$G(j,k)=\left[F(j,k)\right]^{p} \text{ Where p = 2 or 3.} \qquad (1)$$

Where $F(j, k)$ is the image to enhance, $G(j, k)$ the enhanced image and p the power variable. The square function (with $p = 2$) provides a better visual outcome than the cubic function ($p = 3$) [3]. W. K. Pratt recommends normalizing grayscale of pixels before applying the power law [4].

2.2. The modified power law (MPL)

2.2.1. Context

Normalization of grayscales recommended by WK Pratt [4] allows obtaining image which contrast closed to the original one. In the case of very low contrast original image such as those disturbed by noise related to the context of acquisition as dark caused by lack light during photo shooting, the improved image in these conditions has a very low mean value of grayscales. Thus, hidden details cannot be revealed. On the other hand, the application of the PL with $p = 2$ without normalization the grayscales, although it puts out some hidden details, often destroys the image. To overcome these difficulties, we propose a new domain for the power variable *p* that we call *p'*. It allows a much finer variation of contrast, reveals progressively hidden details on the image without destroying this one.

The enhancement of images by the power law presented by William Pratt is suitable for black and white images [3] where we obtain good results with $p = 2$ and $p = 3$. In the case of RGB color images, the method is applicable by considering each channel separately. A discrete image $I\ (x, y)$ is defined as a set E of points and whose grayscales (GS) are integers and situated between two values: a minimum $GS_{min} = 0$ and a maximum $GSmax = M = 255$.

Let be a function I: $E \rightarrow K = \{0, 1, ..., M\}$, with K a set of grayscales, involving a point $n(x, y)$ belonging to E and that is the grayscale $I\left[n\left(x,y\right)\right] = I\left(n\right)$.

Let be *p'* belonging to R^+ such as *p'* Є [1.00, 1.01,... 1.99, 2.00].
Let be f an application such as, for any grayscale k corresponding $f\,(p') = [I\,(n)]^{p'}$ Є K.

Let be k Є K: when $p' \rightarrow +\infty$, $k = 0$ or $k = 1$ if $k = 0$ or 1 and $k = 255$ if $k \neq 0$ or $k \neq 1$ (2)

It follows, therefore, a shift of low grayscale values to 255. The transformed image's histogram will be constituted at the end by only 3 grey levels: 0, 1 and 255. A reduction of the step value of power variable *p'* produces a slow and gradual disappearance of the slight difference, leading to a high color bright contrasted image. When using $p = 2$ or 3 proposed by the author [3], some images disappeared. The *p'* variable helps to reveal hidden details on original image.

It seems difficult to find a metric that allows choosing the best enhanced image and therefore fixing the value of the variable *p'* for a given image.

We propose an approach that allows to set the value of *p'* gives the best image enhancement. This, called direct approach, is based on choosing the maximum value of the signal noise ratio (SNR) of the transformed image that has to be improved. This method exploits the relationship giving the signal noise ratio (SNR) [6] to provide the appropriate value of variable *p'* calculated from each pixel. After obtaining *p'*, it can be apply to the transformed image.

2.2.2 Description of the method

Consider an image with low contrast $I_e\left(x,y\right)$ such as: $I_t\left(x,y\right) = T\left[I_e\left(x,y\right)\right]$ where T is RGB → YC_bC_r and $R_rG_rB_r$ → YC_bC_r transformations; with $I_t\left(x,y\right)$, the transformed image.

Consider $SNR_{\max}$ the maximum value of SNR of the transformed image $I_t\left(x,y\right)$. The improved image by MPL $I_a\left(x,y\right)$ is given by relation (3):

$$I_a\left(x,y\right) = \left[I_t\left(x,y\right)\right]^{p'} \qquad (3)$$

When p' increases, the SNR decreases and the contrast of the image increases.

Let be n_i the grayscale of the transformed image and m_i the grayscale of the image to be enhanced by MPL. Then:

$$m_i = n_i^{p'} \qquad (4)$$

Consider $e_i = n_i - m_i$; let be e_i the error made on the grayscale improved.

Consider $$MSE_i = \frac{\left(n_i - m_i\right)^2}{1} \qquad (5)$$

The mean square error on the grayscale *i*:
The SNR_i defined on this grayscale is:

$$SNR_i = \frac{m_i^2}{\left(n_i - m_i\right)^2} \qquad (6)$$

Developing this relationship, we find:

$$SNR_i n_i^2 - 2n_i m_i SNR_i + SNR_i m_i^2 = m_i^2$$

$$\left(SNR_i - 1\right)m_i^2 - 2n_i SNR_i m_i + SNR_i n_i^2 = 0$$

Solving this equation gives two roots of which the positive is: $$m_{i1} = m_i = n_i \frac{SNRi + \sqrt{SNR_i}}{SNR_i - 1} = n_i^{p'}$$

$$\left(p^{'}-1\right)=\frac{\log_{10}\left(\frac{SNRi+\sqrt{SNR_i}}{SNR_i-1}\right)}{\log_{10}n_i}$$

then $$p^{'}=1+\frac{\log_{10}\left(\frac{SNRi+\sqrt{SNR_i}}{SNR_i-1}\right)}{\log_{10}n_i}$$

$$p'=1+\frac{\log_{10}X}{\log_{10}Z} \qquad (7)$$

with

$$X=\frac{SNR_i+\sqrt{SNR_i}}{SNR_i} \qquad (8)$$

and

$Z=n_i+\varepsilon=I_t\left(x,y\right)+\varepsilon$ such as $1 < \varepsilon \leq 1.00001$ (9)

Thus, from a fixed value of SNR or chosen namely $SNR=\eta * SNR_{\max}$ (10) with η expressed as percentage, it is possible to obtain a *p′* power variable that provides the desired enhanced image. The choice of η is done from the graph of function $\sum SNR=f\left(p'\right)$. This curve determines the range of p' values within which low-contrast images are significantly enhanced.

2.2.3 Algorithms

Algorithm using normalization (WN: With Normalization) of the grayscale is:
1 - Apply RGB → YCbCr transformation and its inverse with truncating the Y, Cb and Cr coefficients on the original image.
2 - Calculate the SNR of the transformed image for each channel R, G and B.
3 - Calculate the sum of the maximum value of SNR: ΣSNR_{max} for all the 3 channels.
4 - Choose η and apply the relationship [10].
5 - Calculate the power variable p' according to relationship (7) for each pixel.
6 - Normalize the grayscale image to improve.
7 - Apply the MPL method on the grayscale normalized.
8 - Reduce the enhanced grayscale in the range [0, 255].
9 - Write the enhanced image by MPL.

Algorithm without normalization (NN: No Normalization) the grayscale is:
1 - Apply RGB→YCbCr transformation and its inverse by truncating Y, Cb and Cr coefficients on the original image.
2 - Calculate the SNR of the transformed image for each channel R, G and B.
3 - Calculate the sum of the maximum value of SNR: ΣSNR_{max} for all the 3 channels.
4 - Choose η and apply the relationship [10].
5 - Calculate the power variable p' according to relationship (7) for each pixel.
6 - Apply the MPL method on the grayscale that is not normalized.
7 - Reduce the enhanced grayscale in the range [0, 255].
8 - Write the enhanced image by MPL.

III. DESCRIPTION OF EXPERIMENTS

Highlighting the truncation noise in images with low contrast is made by applying the RGB →YCbCr transformation followed by its inverse YCbCr→ RGB in which the image reconstructed is done after truncating the Y, Cb, Cr coefficients by removing their decimal parts. The study of this noise has been the subject of a previous paper [9].

A comparative study of the PL is done with normalization and without normalization of grayscales of the transformed image. Another comparative study is made by applying the MPL with and without normalization the grayscale. Before applying the MPL, we determine the power variable p' from the relationship [10].

From this relationship the proportion η of the maximum value of SNR is selected from the graph of the function $\sum SNR=f\left(p'\right)$.
The normalization of grayscale is done by dividing each pixel by the biggest value of grayscale per channel of color image.
We then present the benefits of the MPL method without normalization of grayscale. For each study a statistical analysis of the image's parameters is done.

IV. RESULTS AND ANALYSIS OF RESULTS

4.1 Highlighting the truncation noise in RGB → YCbCr and YCbCr →RGB transformation in two types of images: images with low contrast (Eamac and EamacB) and a normal contrast one (Lena).

4.1.1 Mean values of grayscale of the two types of images. Table 1 shows the mean values of grayscales of the two types of original image.

Table 1: Average of the grayscale of the original images

Means	Eamac	EamacB	Lena
R	12,06	23,62	105,54
G	21,29	35,09	99,06
B	32,37	45,76	180,28

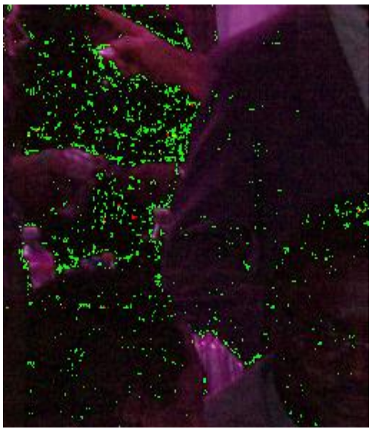
This table shows that the mean of grayscale for Eamac and EamacB images are less than 100 contrary to those of the Lena image. Indeed the two images have more low contrast than Lena (see Figures 1a, 1b, 1c).

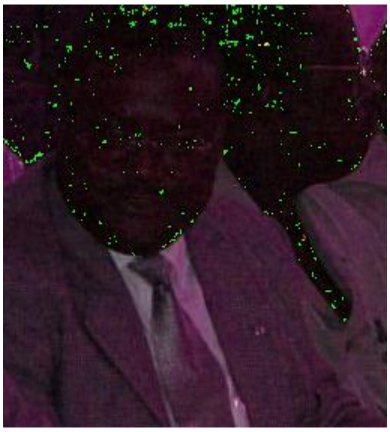
Figure 1a: Original Eamac Figure1b: Original EamacB Figure 1c: Original Lena

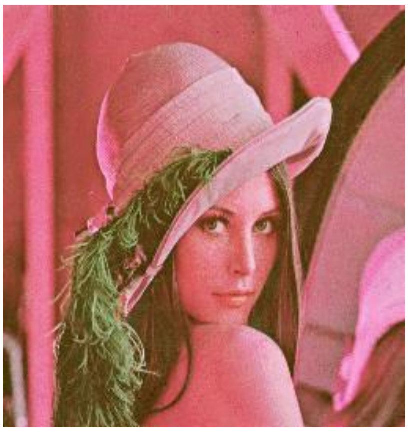
4.1.2 Application of the RGB → YCbCr and YCbCr →RGB transformations

This is to show the influence of the truncation of the Y, Cb and Cr coefficients on low contrast images, more specifically images degraded by black noise due to a very low lighting during photo shooting. This noise is often produced by young amateur photographers of Africa, poorly trained in the shooting techniques.

Figure 2a: Transformed Eamac Figure2b: Transformed EamacB Figure 2c: Transformed Lena







Both images Eamac and EamacB which are disturbed by this noise (black) show another noise after applying transformation, the truncation noise appeared from Y, Cb, Cr coefficients. It appears as green dots distributed randomly on the transformed image. On the contrary, Lena image, which has a high value of grayscale mean, is not affected by these green dots, but presents change in color.

4.2 Application of PL method, with and without normalization the grayscales.

4.2.1 Images enhanced by PL (*p* = 2)

Figure 3a: Eamac with normalization Figure 3b: Eamac without normalization

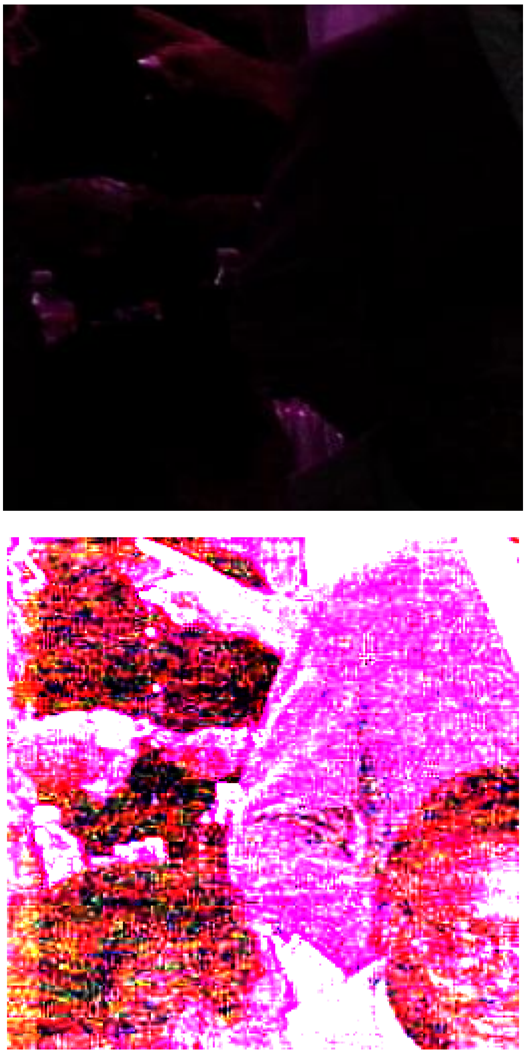


Figure 4a: EamacB with normalization Figure 4b: EamacB without normalization

Figure 5a: Lena with normalization Figure 5b Lena without normalization

Application of PL with *p* = 2 without normalization destroyed completely an image that has highest mean values of grayscale like Lena (Figure 5b). On the other hand, the normalization of coefficients before applying PL gives good results (Figure 5a).

However, normalization of grayscales before application on image with low values of grayscale mean does not remove the dark (Figures 3a and 4a), although the truncation noise disappears.
On the other hand, on such images, the lack of normalization may allow the revelation of certain details initially hidden on the original image (see Figures 3b and 4b), but this revelation is brutal with destruction of image. It therefore seems not necessary to normalize the coefficients r, g, b before the implementation of the PL method, if you will remove noise (black) and reveal some information on low-contrast images taken by young amateur photographers. Coefficients are normalized or not, the truncation noise disappears (see Figures 3a and 4b).

4.2.2 Statistical parameters and analysis of images

Table 2: Statistical parameters of images enhanced with PL (*p* = 2)

Statistical parameters	Eamac		EamacB		Lena	
	N	NN	N	NN	N	NN
R Means G B	1,40 3,83 6,51	98,10 172,38 225,45	4,18 8,24 11,00	173,34 205,38 242,50	53,82 51,12 136,98	254,93 252,17 255,00
R RMS G B	168,61 440,96 837,77	14193,78 30304,80 40653,48	506,48 947,19 1408,17	30183,23 33634,47 40374,01	2715,36 2519,23 2149,96	23502,69 26175,59 8018,79
R SNR (dB) G B	-10,08 -5,93 -6,06	1,00 1,11 1,31	-8,80 -6,88 -6,95	1,24 1,62 1,77	1,92 2,82 10,27	4,42 3,88 9,09
ΣSNR (dB)	-22,07	3,42	-22,63	4,63	15,01	17,39

For low-contrast color images with low mean grayscales values, the PL (p = 2) with normalization gives grayscale images with very low mean values of grey levels (compare Table 2, columns 2 and 4 with Table 1). The normalization of grey levels which reduced their average emphasizes the reduction of contrast (see Figure 3a, 4a, 5a). This reduction does not destroy an image like Lena which is taken under appropriate conditions. On the other hand it degrades low contrast images as Eamac and EamacB. The enhanced images remain very dark with a bad quality as the values of the SNR show it. However, this method (PL) offers the possibility of revealing information initially hidden on the original image when the grayscales to enhance are not normalized. But this revelation is made in a very brutal way leading to the destruction of the image (see Figures 3b and 4b).

The application of PL (p = 2) on Lena provides values **without normalization** of SNR quite large compared to cases with normalization because the enhanced image shows grayscales that most values are close to 255 (see Table 2, column 7). But these values don't provide good image quality (see Figure 5b). The normalization of grey levels before applying the PL (p = 2) is therefore entirely appropriate for images taken under appropriate conditions as the image Lena.

4.3 Study of the function $\Sigma SNR = f(p')$ and choice of the p' range variation.

Before choosing η, it is important to adjust the range of values of p' that effectively enable an enhancement of low contrast image. For both images Eamac and EamacB, the results are shown in Figures 6a and 6b.

4.4 Enhancing low contrast image by using MPL

a- Choosing variable p'

The choice of p' is fixed by η. The study of the function $\Sigma SNR = f(p')$ provides a curve that allows a more appropriate choice of the variable p'. The proportions η which allow this choice are between η = 25% and η = 2%. The results of this study appear on tables 3a to 3f. The corresponding images clearly show that enhancement is progressive and the values of p' increase slowly and not brutally.

Figure 6a: Graph $\Sigma SNR = f(p')$ for Eamac:

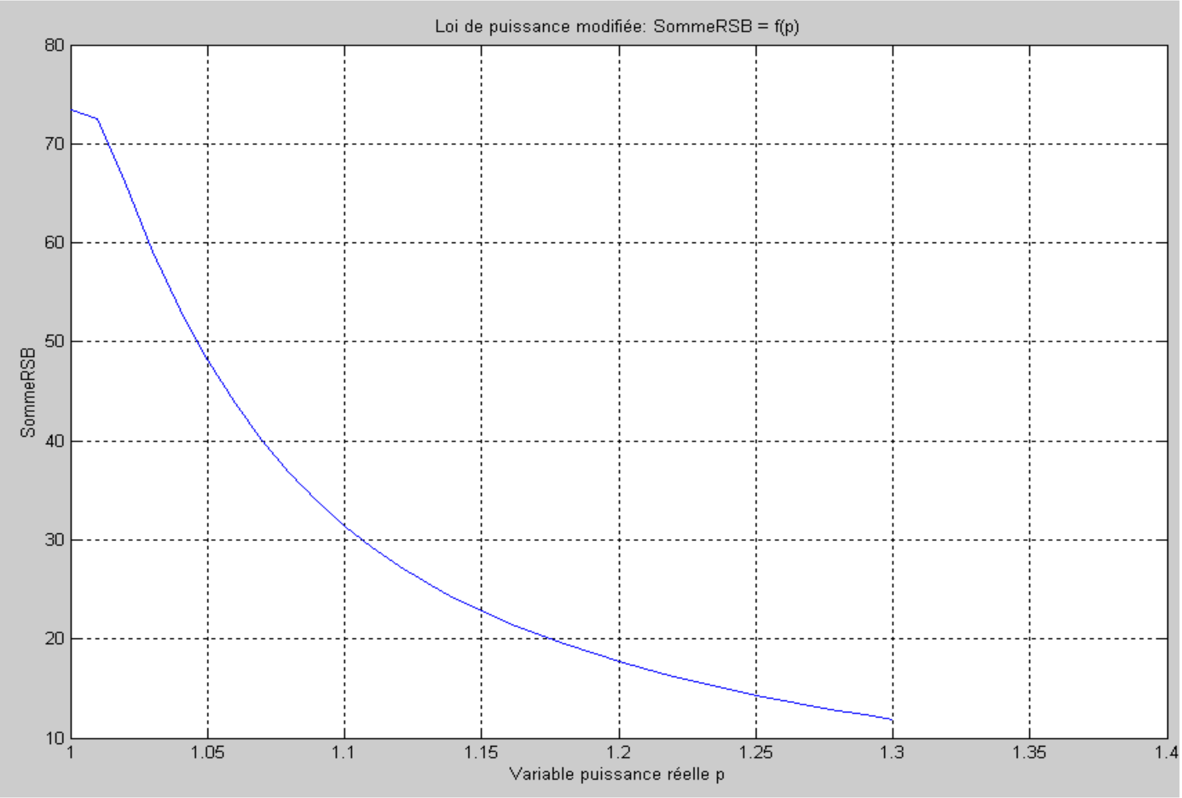


Figure 6b: Graph *ΣSNR = f (p')* for EamacB:

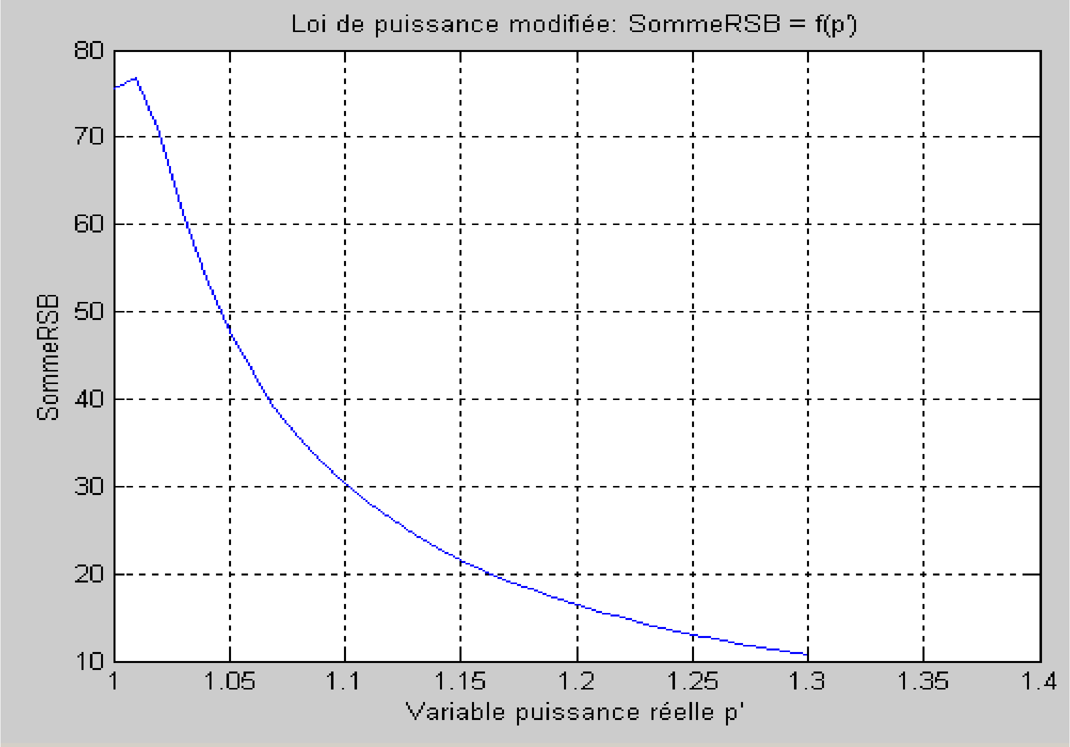


Table 3a: Power variable p' per channel, for η = 25% and statistical parameters:

Power variable Images	Channel R : P'_{Rmean}	Channel G : P'_{Gmean}	Channel B : P'_{Bmean}	P'_{mean}
Eamac	1.0357	1.0881	1.0790	1.0676
EamacB	1.0625	1.0724	1.0672	1.0673
Lena	1.0444	1.0477	1.0397	1.0439

Statistical parameters	Eamac	EamacB	Lena
R Mean G B	13.05 26.30 39.08	27.36 43.36 55.33	126.62 120.10 211.02
R RMS G B	10.22 60.29 95.29	35.59 114.36 139.67	505.46 581.00 1050.48
R SNR (dB) G B	15.35 13.53 14.20	15.36 14.01 14.69	15.47 15.06 16.55
ΣSNR (dB)	47.08	44.06	47.07

Figure7: Eamac25%.bmp EamacB25%.bmp Lena25%.bmp

Table 3b: Power variable p’ per channel, for η = 20% and statistical parameters:

Power variable Images	Channel R : P'_{Rmean}	Channel G : P'_{Gmean}	Channel B : P'_{Bmean}	P'_{mean}
Eamac	1.0519	1.1019	1.0904	1.0814
EamacB	1.0749	1.0832	1.0765	1.0782
Lena	1.0503	1.0540	1.0450	1.0497

Statistical parameters	Eamac	EamacB	Lena
R	13.50	28.26	130.00
Mean G	27.26	44.78	123.24
B	40.51	57.15	213.91
R	14.26	50.23	678.33
RMS G	82.65	155.29	762.78
B	133.51	193.97	1256.45
R	14.20	14.15	14.42
SNR (dB) G	12.47	12.96	14.09
B	13.04	13.55	15.87
ΣSNR (dB)	39.71	40.66	44.39

Figure8: Eamac20%.bmp EamacB20%.bmp Lena20%.bmp

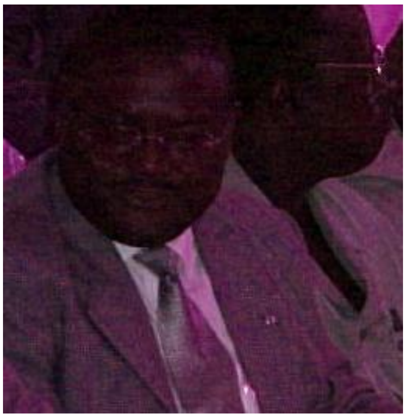


Table 3c: Power variable p’ per channel, for η = 15% and statistical parameters:

Power variable Images	Channel R : P'_{Rmean}	Channel G : P'_{Gmean}	Channel B : P'_{Bmean}	P'_{mean}
Eamac	1.0767	1.1231	1.1080	1.1026
EamacB	1.0938	1.0997	1.0908	1.0947
Lena	1.0593	1.0636	1.0530	1.0586

Statistical parameters	Eamac	EamacB	Lena
R	14.24	29.71	135.46
Mean G	28.73	47.09	127.94
B	42.72	60.08	217.78
R	22.85	79.53	1009.69
RMS G	124.89	234.01	1072.11
B	206.95	299.13	1571.86
R	12.62	12.59	13.05
SNR (dB) G	11.14	11.62	12.92
B	11.60	12.10	15.03
ΣSNR (dB)	35.36	36.31	41.01

Figure9: Eamac15%.bmp EamacB15%.bmp Lena15%.bmp

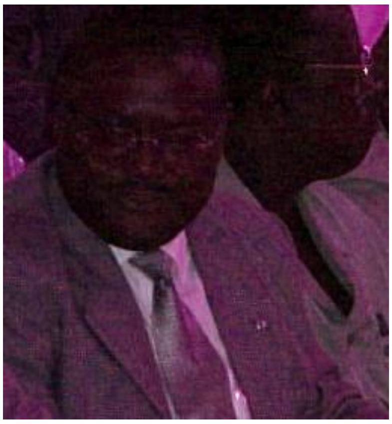


Table 3d: Power variable p’ per channel, for η = 10% and statistical parameters:

Power variable Images	Channel R : P'_{Rmean}	Channel G : P'_{Gmean}	Channel B : P'_{Bmean}	P'_{mean}
Eamac	1.1216	1.1614	1.1398	1.1409
EamacB	1.1278	1.1293	1.1164	1.1245
Lena	1.0752	1.0807	1.0672	1.0743

Statistical parameters	Eamac	EamacB	Lena
R	15.75	32.49	145.47
Mean G	31.75	51.43	136.28
B	47.15	65.69	223.96
R	46.63	155.43	1779.44
RMS G	235.08	427.77	1742.16
B	399.39	565.36	2180.59
R	10.39	10.46	11.20
SNR (dB) G	9.24	9.77	11.32
B	9.60	10.11	13.82
ΣSNR (dB)	29.23	30.34	36.82

Figure10: Eamac10%.bmp EamacB10%.bmp Lena10%.bmp

Table 3e: Power variable p’ per channel, for η = 5% and statistical parameters:

Power variable Images	Channel R : P'_{Rmean}	Channel G : P'_{Gmean}	Channel B : P'_{Bmean}	P'_{mean}
Eamac	1.2427	1.2649	1.2256	1.2444
EamacB	1.2180	1.2079	1.1842	1.2033
Lena	1.1159	1.1244	1.1036	1.1146

Statistical parameters	Eamac	EamacB	Lena
R	20.35	41.07	171.26
Mean G	41.17	65.20	157.71
B	61.07	83.24	234.89
R	182.11	550.99	4634.18
RMS G	795.84	1422.55	4203.39
B	1374.08	1939.22	3569.62
R	6.74	7.01	8.37
SNR (dB) G	6.15	6.61	8.63
B	6.39	6.81	12.01
ΣSNR (dB)	19.28	20.43	29.01

Figure11: Eamac5%.bmp EamacB5%.bmp Lena5%.bmp

Table 3f: Power variable p’ per channel, for η = 2% and statistical parameters:

Power variable Images	Channel R : P'_{Rmean}	Channel G : P'_{Gmean}	Channel B : P'_{Bmean}	P'_{mean}
Eamac	1.6634	1.6242	1.5236	1.6037
EamacB	1.5060	1.4587	1.4009	1.4552
Lena	1.2299	1.2467	1.2055	1.2273

Statistical parameters	Eamac	EamacB	Lena
R	49.24	85.01	234.55
Mean G	92.85	130.35	204.49
B	132.54	161.83	253.39
R	2905.51	5917.09	17246.86
RMS G	7763.91	12745.96	12837.39
B	12580.81	16414.48	7515.60
R	2.23	2.77	5.11
SNR (dB) G	2.34	2.74	5.65
B	2.51	2.91	9.32
ΣSNR (dB)	7.08	8.42	20.08

Figure11: Eamac2%.bmp EamacB2%.bmp Lena2%.bmp

By varying the values of η from 25% to 2%, the low contrast image enhancement is effective.

Hidden details reveal themselves as η decreases. However a normal contrast image like Lena degrades gradually. Directly applying the modified power law (MPL) without normalization low contrast images gives a good result. See Figure11, the two first images.

V. CONCLUSION

MPL offers finer improvement opportunities because it provides multiple values of the variable *p'*. This allows obtaining different contrasts and facilitating the choice of improved images. Normalization of grayscales before applying MPL does not bring contrast enhancement in very low-contrast images. Images subject to the black noise are effectively improved. In this context, the modified power law is a powerful tool for enhancement of low-contrast photographic color image.

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VII. ANNEX

Transformations of color spaces and the statistical parameters used in this article are presented in this section.

7.1 The transformation of color spaces RGB → YCbCr and RGB → YCbCr [7] [8]:

Y = 0.299R + 0.587G + 0.114B
Cb = - 0.1687R – 0.3313G + 128
Cr = - 0.5R – 0.4187G – 0.081B + 128
And
R = Y +1.402 (Cr – 128)
G=Y-0.34414 (Cb–128) – 0.71414 (Cr – 128)
B=Y + 1.772 (Cb – 128)

7.2 The statistical parameters [6]

a- Mean M gray levels of pixels of an image:

$$Moy = \frac{\sum_{j=1}^{j=M} \sum_{k=1}^{k=N} ng\left(j,k\right)}{M \cdot N}$$

with: ng (j, k), the grayscale of pixel at position (j, k) and M. N the image size.

b. Mean squared error MSE:

$$EQM = \frac{1}{M \cdot N} \sum_{j=1}^{j=M} \sum_{k=1}^{k=N} \left[f\left(j,k\right) - g\left(j,k\right) \right]^2$$

$M \cdot N$: image size

$f\left(j,k\right)$: original image

$g\left(j,k\right)$: degraded or transformed image

Where f (j, k) - g (j, k) is the difference between the gray level input and the output.

c. Signal to noise ratio (SNR):

$$RSB = 10 \log_{10} \frac{\frac{1}{M \cdot N} \sum_{j=1}^{j=M} \sum_{k=1}^{k=N} \left[g\left(j,k\right) \right]^2}{EQM} \left(dB\right)$$