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RESEARCH

Global model for uneven illumination enhancement of document images

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Abstract

Exponential growth of low-cost digital imagery is latterly observed. Images acquired under uneven lighting are prone to experience poor visibility, which may severely limit the performance of most computational photography and automatic visual recognition applications. Different from current optimization techniques, we design a novel partial differential equation based model to rectify the variable illumination artifacts. In this study, a large number of document samples capturing uneven illumination and low contrast conditions are tested to compare the effectiveness of the proposed local and nonlocal approaches. The suggested algorithm can be applied in Arabic, Latin and Chinese document images with any type of shade.

Keywords: Document image processing; Illumination enhancement; Nonlinear diffusion; Nonlocal p-Laplacian

1 Introduction

With the current digital revolution and the availability of a wide range of image-capturing devices such as digital cameras, digital camcorders, smartphones and scanners, document imaging has replaced paper files and documents as a vital medium to transmit information in people's life. However, by virtue of the effect of the shooting environment, the document images may undergo from various distortions.

Bad illumination is among the major factors affecting the image formation. It naturally leads to uneven global brightness due to dissimilar texture of the object surface and the shadows produced from distinct light source directions. A non-uniform light distribution, unstable lighting and the shade of other objects in the scene represent mainly the nonideal conditions under which unevenly illuminated images are acquired. This distortion leads to an extreme quality degradation of document images and may confuse the interpretation of their content which necessarily poses significant and notable problems in the subsequent layout analysis and the character recognition stages. Consequently, correcting illumination on document images can considerably enhance the performance of subsequent analysis tasks.

Non-uniform illumination enhancement shines in many vision-based applications. Within the context of medical imaging, Grisan et al. [1] proposed an effective algorithm to model and correct the local luminosity and the variability of the contrast in non-uniformly illuminated Retinal images, whereas in [2], a shading correction procedure of the digital microscopy images is outlined, it is based upon the intrinsic properties of the image, which are revealed through Gaussian smoothing. Illumination correction is also a crucial step in pre-processing high-resolution remote sensing

data for forest change detection studies [3], satellite images [4] or for remote sensing images covered by thin clouds [5]. Another of the most important problems of illumination normalization is face recognition under varying illumination [6] and object tracking in video sequences [7].

The goal of illumination enhancement algorithms is to weaken as much as possible the effects of the present shade or bright light. As part of document images processing, traditional procedures commonly adopt adaptive binarization methods [8] [9] to eliminate the shadow. Knowing that the lighting of a document image often varies slowly, homomorphic filters [10] can be employed to subtract the background from the initial image, these filters produce satisfactory outputs for the textual parts of the images, but unfortunately can damage photographic regions. The illumination-balance algorithm [11] can efficiently improve the quality of degraded document images with illustrations obtained by scanners. This technique translates into four distinct stages: edge detection step using Sobel edge detector in several directions, object mark step, light evaluation step, and illumination balance step. This technique is then improved in [12]. Meng et al [13] defined a Convex Hull to estimate the shading for scanned document images.

The crucial objective of this work is to present an improved non-local approach for estimating variable illumination in document images. From a physical standpoint, nonlocal approaches play a vital rule in characterizing many natural phenomena. The concern for nonlocal methods is motivated by the ability of these approaches to capture with rigorous accuracy the effects that are difficult to describe by local models. Nonlocal functionals, nonlocal operators and nonlocal problems defined in nonlocal function spaces, have gradually attracted the mathematical community's attention by its theoretical wealth, as for its concrete real-world applications. This type of model occurs in a quite natural way in many different contexts, such as, among others, continuum theory [14], physics-based nonlocal elasticity [15], machine learning [16] and phase transition [17], and so on.

To tackle the problem of varying illumination in document images, we introduce in this paper an effective a nonlocal p-Laplacian based equation to estimate the illumination component of the degraded source image. The proposed approach inherits the advantages of the nonlocal models in preserving text textures and small details.

2 The proposed model

In this section, we formulate a non-local evolution equation to correct the document images acquired under variable illumination. Starting with a grayscale image, our evolution equation estimates the non-uniform illumination to offer a perfectly clear version of the initial image.

2.1 Derivation of the proposed model

According to Reintal-Cortex theory [18], a given image " U " can be decomposed as follows:

$$U(x, y) = I(x, y)R(x, y) \quad (1)$$

$I(x, y)$ stands for the illuminated part of ambient light and $R(x, y)$ represents the reflected constituent of the real color of the object.

The aim of this work is eliminating the effect of the component "I" and acquiring the text component of the original document image. For illumination estimation, Ait Bella et al. [19] explain that when the image contains only text, the intensity of the variable illumination background takes on values greater than the intensity of the dark text, which allows to approximate the illumination by replacing each pixel with the maximum average of its neighboring pixels. In essence, if I_{ij}^n represents the intensity of a pixel (i, j) at the n^{th} iteration, we get:

$$I_{ij}^{n+1} = \max \left(I_{ij}^n, \frac{I_{i+1j}^n + I_{i-1j}^n}{2}, \frac{I_{ij+1}^n + I_{ij-1}^n}{2}, \frac{I_{i+1j+1}^n + I_{i-1j-1}^n}{2}, \frac{I_{i-1j+1}^n + I_{i+1j-1}^n}{2} \right), \quad (2)$$

By subtracting I_{ij}^n from both sides of the equation (2), the discrete second derivatives in all directions appear and we obtain the discretized version of the equation:

$$\frac{\partial I}{\partial t} = \frac{1}{2} \max \left(0, \frac{\partial^2 I}{\partial x^2}, \frac{\partial^2 I}{\partial y^2}, \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2} + 2 \frac{\partial^2 I}{\partial x \partial y}, \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2} - 2 \frac{\partial^2 I}{\partial x \partial y} \right) \quad (3)$$

In a similar manner, taking into account only the vertical and horizontal directions, one can directly consider the Laplacian operator instead of the second derivatives. Inspired by [19], we propose the following nonlinear equation as the diffusion process of our illumination estimation model:

$$\begin{cases} \frac{\partial I}{\partial t} &= \max(0, \operatorname{div}(|\nabla I|^{p-2} \nabla I)) & \text{in } (0, T) \times \Omega \\ \frac{\partial I}{\partial n} &= 0 & \text{on } \partial\Omega \times (0, T) \\ I(., 0) &= I_0 & \text{in } \Omega \end{cases} \quad (4)$$

where $1 < p < \infty$ and Ω is a bounded open subset of $\mathbb{R}^2$.

The p-Laplacian $\Delta^p I = \operatorname{div}(|\nabla I|^{p-2} \nabla I)$ has attracted much attention in various applications. For instance, it arises in non-Newtonian fluids, flow through porous media, reaction-diffusion problems, nonlinear elasticity or in petroleum extraction. It should be mentioned that when $p = 2$, the proposed results coincide with those of the article [19]. Our central idea is to adopt a non-linear generalization of the standard Laplacian for the sole purpose of correcting any non-uniform illumination effect by controlling the degree of smoothing by different choices of the exponent "p".

In this article, we deal with the evolutionary equation (4), we give an existence result for the solutions of the proposed model (4) within the framework of the theory of viscosity solutions [20].

2.1.1 Preliminaries

The theory of viscosity solutions applies to several partial differential equations, including the equation of the form:

$$\frac{\partial I}{\partial t} + F(\nabla I, \nabla^2 I) = 0, \quad \text{in } Q_t = (0, T) \times \Omega \quad (5)$$

Where Ω is a domain in $\mathbb{R}^n$. F is a real-valued function on $\mathbb{R}^n \times S^n$, where S^n stands for the set of symmetric $n \times n$ matrices, ∇I and $\nabla^2 I$ denote respectively, the gradient and the Hessian matrix of I in space variables.

To determine viscosity solutions, it is necessary to introduce a class of "test functions".

Definition 1 [21] *A function $\varphi \in C^2(Q_T)$ is admissible, in short $\varphi \in \mathcal{A}(F)$, if for any $\hat{z} = (\hat{t}, \hat{x}) \in Q_T$ with $\nabla \varphi(\hat{z}) = 0$, there exist a constant $\delta > 0$, $f \in \mathcal{F}(F)$ and $\omega \in C[0, \infty)$ satisfying $\omega \geq 0$ and $\lim_{r \rightarrow 0} \omega(r)/r = 0$ such that*

$$|\varphi(z) - \varphi(\hat{z}) - \frac{\partial \varphi}{\partial t}(\hat{z})(t - \hat{t})| \leq f(|x - \hat{x}|) + \omega(|t - \hat{t}|) \quad (6)$$

for all $z = (t, x)$ with $|z - \hat{z}| < \delta$.

Now we shall introduce a notion of viscosity solutions of (5).

Definition 2 [21] *Assume that (H1) and (F2) hold and that $\mathcal{F}(F)$ is not empty.*

1. *A function $u : Q_T \rightarrow \mathbb{R} \cup \{-\infty\}$ is a viscosity subsolution of (5) if $u^* < +\infty$ on $\bar{Q}_T$ and for all $\varphi \in \mathcal{A}(F)$ and all local maximum point z of $u^* - \varphi$ in Q_T ,*

$$\begin{cases} \frac{\partial \varphi}{\partial t}(z) + F(\nabla \varphi(z), \nabla^2 \varphi(z)) \leq 0 & \text{if } \nabla \varphi(z) \neq 0, \\ \frac{\partial \varphi}{\partial t}(z) \leq 0 & \text{otherwise.} \end{cases} \quad (7)$$

2. *A function $u : Q_T \rightarrow \mathbb{R} \cup \{-\infty\}$ is a viscosity supersolution of (5) if $u_* > -\infty$ on $\bar{Q}_T$ and for all $\varphi \in \mathcal{A}(F)$ and all local minimum point z of $u_* - \varphi$ in Q_T ,*

$$\begin{cases} \frac{\partial \varphi}{\partial t}(z) + F(\nabla \varphi(z), \nabla^2 \varphi(z)) \geq 0 & \text{if } \nabla \varphi(z) \neq 0, \\ \frac{\partial \varphi}{\partial t}(z) \geq 0 & \text{otherwise.} \end{cases} \quad (8)$$

3. *A function u is called a viscosity solution of (5) if u is both a viscosity sub- and super-solution of (5).*

We appoint the hypotheses of F which are important to consider the viscosity solution for constructing a viscosity solution of (5) by Perron's method:

- (H1) F is continuous in $(\mathbb{R}^n \setminus \{0\}) \times S^n$.
- (H2) F is degenerate elliptic, i.e, if $X \geq Y$, then $F(q, X) \leq F(q, Y)$ for all $q \in (\mathbb{R}^n \setminus \{0\})$.
- (H3) $\mathcal{F}(F) \neq \emptyset$ where $\mathcal{F}(F)$ is the set of functions $f \in C^2[0, \infty)$ which satisfies.

$$f(0) = f'(0) = f''(0), \quad f''(r) > 0 \quad \text{for all } r > 0, \quad (9)$$

and

$$\lim_{|x| \rightarrow 0, x \neq 0} F(\nabla f(|x|), \nabla^2 f(|x|)) = 0. \quad (10)$$

- (H4)₊ There exists $g \in \mathcal{G} := \{g \in C^2[0, \infty); g(0) = g'(0) = 0, g'(r) > 0 \text{ if } r > 0, \lim_{r \rightarrow 0} g(r) = \infty\}$ such that for all $A > 0$, there is B such that

$$F(\nabla(Ag(|x|)), \nabla^2(Ag(|x|))) \geq -B \quad \text{for all } x \in \mathbb{R}^N \setminus \{0\}. \quad (11)$$

- (H4)₋ There exists $g \in \mathcal{G}$ such that for all $A > 0$, there is B such that

$$F(\nabla(-Ag(|x|)), \nabla^2(-Ag(|x|))) \leq B \quad \text{for all } x \in \mathbb{R}^N \setminus \{0\}. \quad (12)$$

2.1.2 Existence theorem

Theorem 1 Let Ω be a regular bounded open subset of $\mathbb{R}^2$ and $I_0(x) \in UC(\mathbb{R}^2)$. Then there exists a unique viscosity solution of the proposed model (4).

Proof 1 In order to place the equation (4) in the form (5), we rewrite:

$$\begin{aligned} F(\nabla I, \nabla^2 I) &= -\max(0, \operatorname{div}(|\nabla I|^{p-2} \nabla I)) \\ &= -H \left(|\nabla I|^{p-2} \operatorname{trace} \left(\left(Id + (p-2) \frac{\nabla I \otimes \nabla I}{|\nabla I|^2} \right) \nabla^2 I \right) \right) \\ &\quad \times |\nabla I|^{p-2} \operatorname{trace} \left(\left(Id + (p-2) \frac{\nabla I \otimes \nabla I}{|\nabla I|^2} \right) \nabla^2 I \right). \end{aligned}$$

where $\otimes$ denotes the tensor product, $Id = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, where H is the Heaviside step function, defined by

$$\forall x \in \mathbb{R}, \quad H(x) = \begin{cases} 0 & \text{if } x < 0 \\ 1 & \text{if } x \geq 0 \end{cases} \quad (13)$$

The function F satisfies the assumptions (H) listed above. In fact:

- F is continuous as composed of the two continuous functions:

$$\begin{aligned} F_1 : \mathbb{R}^2 \times S^2 &\rightarrow \mathbb{R} \\ (q, X) &\mapsto -|q|^{p-2} \operatorname{trace} \left(\left(Id + (p-2) \frac{q \otimes q}{|q|^2} \right) X \right) \end{aligned} \quad (14)$$

and

$$\begin{aligned} F_2 : \mathbb{R} &\rightarrow]-\infty, 0] \\ x &\mapsto H(-x)x \end{aligned}$$

- The degenerate ellipticity of F comes from the degenerate ellipticity of F_1 and the increasing nature of F_2 .
- For $1 < p < 2$, we can easily verify that $f(r) = r^{1+\alpha}$ with $\alpha > 1/(p-1)$ is a function in $\mathcal{F}(F)$. Whereas, we select $f(r) = r^4 \in \mathcal{F}(F)$ for $p \geq 2$.
- Following [21], we also state that $g_1(r) = \frac{p-1}{p} r^{\frac{p-1}{p}} \in \mathcal{G}$ for $1 < p < 2$ and the function $g_2(r) = r - \arctan(r)$, for $p > 2$ satisfy (H4)_±.

According to the theorem 4.8 in [21], we obtain the existence of a unique viscosity solution $I \in UC([0, T) \times \mathbb{R}^2)$ to the following problem:

$$\begin{cases} \frac{\partial I}{\partial t} + F(\nabla I, \nabla^2 I) = 0 & \text{in } (0, T) \times \mathbb{R}^2 \\ I(\cdot, 0) = I_0 & \text{in } \mathbb{R}^2 \end{cases} \quad (15)$$

In particular, this solution can be defined on $D \times [0, T)$, where $\Omega \subset \subset D$. By Perron's method, we obtain existence of a viscosity solution $\tilde{I}$ on $D \times [0, T)$, then with the localization property [22] $\tilde{I}|_{\Omega \times (0, T)}$ is a viscosity solution of the differential equation that satisfies the initial condition in the classical sense as well. The viscosity solution $\tilde{I}$ satisfies the differential equation on $\partial\Omega \times (0, T)$ and thus $\tilde{I}|_{\Omega \times (0, T)}$ satisfies the Neumann boundary condition in the viscosity sense.

2.2 A nonlocal extension

The previous subsection provided initial formulation of the proposed model. The goal is to restore and reconstruct the badly illuminated documents in such a way that the text will be easily readable on the output document images but since document images can contain even more redundancy than other forms of images, we propose to modify the equation (4) in an attempt to better restore degraded documents. To achieve this goal, a nonlocal strategy looks like a potential breakthrough. In fact, the basic idea is to avail the self-similarity commonly present in natural as well as document images. Thus, to take benefit of the redundancy and self-similarity of the information in the document images, we propose the following nonlocal analogous problem to (4) with homogeneous Neumann boundary conditions:

$$\begin{cases} \frac{\partial I}{\partial t} = \max(0, \Delta_{NL}^p I) & \text{in } \Omega, t > 0 \\ I(x, 0) = I_0 & \text{in } \Omega \end{cases} \quad (16)$$

where

$$\Delta_{NL}^p I := \int_{\Omega} J(x - y) |I(y, t) - I(x, t)|^{p-2} (I(y, t) - I(x, t)) dy \quad (17)$$

is the nonlocal p-Laplacian operator, $J : \mathbb{R}^2 \rightarrow \mathbb{R}$ is a nonnegative continuous radial function and $1 < p < +\infty$.

The use of the non-local p-Laplacian (17) allows a powerful estimation process and since it does not rely on the gradient to extract the direction of diffusion, the proposed model proves capable of preserving the textures and details of the text.

3 Results and discussion

This section is devoted to the experimental part to evaluate the effectiveness of our method. In order to numerically approach the problem (16), we choose the weight function J which appears in the definition of the non-local p-Laplacian as:

$$J(x) := \begin{cases} \exp\left(\frac{-|x|^2}{h^2}\right) & \text{if } |x| < d, \\ 0, & \text{if } |x| \geq d. \end{cases} \quad (18)$$

where h and d are fixed positive constants.

We consider the following discretization of the nonlocal p-Laplacian operator:

$$\Delta_{NL}^p(u_i) = \sum_{j \in \mathcal{N}_i} J_i |I_j - I_i|^{p-2} (I_j - I_i) \quad j \in \mathcal{N}_i, \quad (19)$$

where I_i and J_i are respectively the value of a pixel i ($1 \leq i \leq N$) and the discrete version of the weight function $J(i-j)$, $\mathcal{N}_i = \{j : |i-j| \leq d\}$ denotes the neighbors set of the pixel i .

The detailed steps of the proposed method are as follows:

- **Input :** The acquired image I_0 ,
- **Initialization :** We set $I^0 = \log(I_0 + 1)$, and choose $dt > 0$, $h > 0$, $k_1, k_2 > 0$,
- **Compute :** $I_i^{n+1} = I_i^n + dt \max(0, \Delta_{NL}^{p(|\nabla I_0|)}(I_i^n)) \quad i = 1, \dots, N$,
- **Output :** The reflectance $R = \exp(\log(I_0 + 1) - I)$.

As the selection of the exponent "p" directly affects the efficiency of the proposed algorithm, this choice always raises questions. In this work we propose to choose it depending on the local gradient of the initial image, such as:

$$p(|\nabla I_0|) = 1 + k_1 \exp(-k_2 |\nabla I_0|), \quad k_1 > 0, k_2 > 0 \quad (20)$$

This function is carefully chosen so that its value is strictly between 1 and 2 if illumination changes and shadows are severe and that the value of "p" is greater than or equal to 2 if illumination variations are regular.

The parameters for our nonlocal model are set as follows: $h = 80$, $k_1 = 5$ and $k_2 = 0.1$.

We have experimented on a number of document images with challenging illumination conditions. Then, we also experimented with the document images from Handwritten Document Image Binarization Contest (H-DIBCO) dataset.

Figs.1-3 compare the results obtained using model 4 with $p = 2$, ie by considering the usual Laplacian operator with those of the proposed local p-Laplacian model and finally with the text recovered by the proposed nonlocal model 16.

Figure 1: **Images enhancement results:** (a) Original degraded image, (b) Recovered reflectance by the proposed nonlocal model (4) with $p=2$, (c) Recovered reflectance by the proposed nonlocal model (4), (d) Recovered reflectance by the proposed nonlocal model (16).

Figure 2: **Images enhancement results:** (a) Original degraded image, (b) Recovered reflectance by the proposed nonlocal model (4) with $p=2$, (c) Recovered reflectance by the proposed nonlocal model (4), (d) Recovered reflectance by the proposed nonlocal model (16).

typical results are shown in Figure 2 and Figure 3. For SRCR, it seems to have some difficulty enhancing image in underexposed and overexposed regions. The luminance addition in the darker regions is insufficient and unnatural, and halo artifacts are introduced which caused bigger σ_{std} . For the original ALMF, it is easy to brighten overexposed regions losing information in highlight regions to have the "blowing out" artifact and enlarge the block effect. However, the proposed method possesses more details with high visual quality in non-uniform lighting conditions than ALMF. Just as discussed in [6], the histogram shows the characteristics of the image, the visibility should be preserved before and after LR, Figure 4(d) shows that the shadow region in the original image shifts to the better luminance range, and the sky region almost unchanged, for more displayed results, the proposed method can restore local details and global contrast. Especially for these degraded images in format of .jpg, our method does not amplify the block effect badly. Besides the subjective evaluation, values of objective standards are listed in Table 1.

(a)

typical results are shown in Figure 2 and Figure 3. For SRCR, it seems to have some difficulty enhancing image in underexposed and overexposed regions. The luminance addition in the darker regions is insufficient and unnatural, and halo artifacts are introduced which caused bigger σ_{std} . For the original ALMF, it is easy to brighten overexposed regions losing information in highlight regions to have the "blowing out" artifact and enlarge the block effect. However, the proposed method possesses more details with high visual quality in non-uniform lighting conditions than ALMF. Just as discussed in [6], the histogram shows the characteristics of the image, the visibility should be preserved before and after LR, Figure 4(d) shows that the shadow region in the original image shifts to the better luminance range, and the sky region almost unchanged, for more displayed results, the proposed method can restore local details and global contrast. Especially for these degraded images in format of .jpg, our method does not amplify the block effect badly. Besides the subjective evaluation, values of objective standards are listed in Table 1.

(b)

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(c)

typical results are shown in Figure 2 and Figure 3. For SRCR, it seems to have some difficulty enhancing image in underexposed and overexposed regions. The luminance addition in the darker regions is insufficient and unnatural, and halo artifacts are introduced which caused bigger σ_{std} . For the original ALMF, it is easy to brighten overexposed regions losing information in highlight regions to have the "blowing out" artifact and enlarge the block effect. However, the proposed method possesses more details with high visual quality in non-uniform lighting conditions than ALMF. Just as discussed in [6], the histogram shows the characteristics of the image, the visibility should be preserved before and after LR, Figure 4(d) shows that the shadow region in the original image shifts to the better luminance range, and the sky region almost unchanged, for more displayed results, the proposed method can restore local details and global contrast. Especially for these degraded images in format of .jpg, our method does not amplify the block effect badly. Besides the subjective evaluation, values of objective standards are listed in Table 1.

(d)

Figure 3: **Images enhancement results:** (a) Original degraded image, (b) Recovered reflectance by the proposed nonlocal model (4) with $p=2$, (c) Recovered reflectance by the proposed nonlocal model (4), (d) Recovered reflectance by the proposed nonlocal model (16).

Figure 4: **Images enhancement results:** (a) Original degraded images, (b) Recovered digits by the proposed nonlocal model (4), (c) Recovered digits by the proposed nonlocal model (16),

Figure 5: **Images enhancement results from H-DIBCO:** (a) Original degraded images, (b) Recovered text by the proposed nonlocal model (16).

The consideration of the local Laplacian operator in the proposed model limits the performance of the proposed approach, we clearly see that the effects of non-uniform illumination are not definitively eliminated, the proposed local model can get rid of these undesirable effects, while the proposed nonlocal model manages to eliminate all degradations while keeping all the details of the text. Fig.4 asserts that the proposed non-local approach is also capable of enhancing bar codes and digits even if this type of image is generally very difficult to model. The last figure shows the results obtained by the proposed non-local model using three selected document images with degrading illumination from (H-DIBCO) dataset.

4 Conclusions

In this paper, we have introduced two novel document image enhancement approaches that can be applied on both handwritten document and machine-printed images. The idea is essentially based on the estimation of the variation of background illumination of the degraded source image then we subtract the estimate component from the input document image to attain a comfortably readable text. We have given an existence result for the solutions of the local proposed model within the framework of the theory of viscosity solutions and we have proposed a particular choice of the exponent "p" which adapts to any type of shade. Our proposed nonlocal approach shows outstanding performance in experiments.

Abbreviations

Not applicable.

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References

1. Grisan, E., Giani, A., Ceseracciu, E., Ruggeri, A.: Model-based illumination correction in retinal images. In: 3rd IEEE International Symposium on Biomedical Imaging: Nano to Macro, 2006., pp. 984–987 (2006). IEEE
2. Leong, F.W., Brady, M., McGee, J.O.: Correction of uneven illumination (vignetting) in digital microscopy images. *Journal of clinical pathology* **56**(8), 619–621 (2003)
3. Tan, B., Masek, J.G., Wolfe, R., Gao, F., Huang, C., Vermote, E.F., Sexton, J.O., Ederer, G.: Improved forest change detection with terrain illumination corrected landsat images. *Remote Sensing of Environment* **136**, 469–483 (2013)
4. Du, Y., Cihlar, J., Beaubien, J., Latifovic, R.: Radiometric normalization, compositing, and quality control for satellite high resolution image mosaics over large areas. *IEEE Transactions on Geoscience and Remote Sensing* **39**(3), 623–634 (2001)
5. Shen, X., Li, Q., Tian, Y., Shen, L.: An uneven illumination correction algorithm for optical remote sensing images covered with thin clouds. *Remote Sensing* **7**(9), 11848–11862 (2015)
6. Chen, T., Yin, W., Zhou, X.S., Comaniciu, D., Huang, T.S.: Illumination normalization for face recognition and uneven background correction using total variation based image models. In: 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05), vol. 2, pp. 532–539 (2005). IEEE
7. Nayak, A., Chaudhuri, S.: Automatic illumination correction for scene enhancement and object tracking. *Image and vision computing* **24**(9), 949–959 (2006)
8. Gatos, B., Pratikakis, I., Perantonis, S.J.: Adaptive degraded document image binarization. *Pattern recognition* **39**(3), 317–327 (2006)
9. Sauvola, J., Pietikäinen, M.: Adaptive document image binarization. *Pattern recognition* **33**(2), 225–236 (2000)
10. Gonzales, R.C., Woods, R.E.: Digital image processing. Prentice hall New Jersey (2002)
11. Lee, J.-S., Chen, C.-H., Chang, C.-C.: A novel illumination-balance technique for improving the quality of degraded text-photo images. *IEEE Transactions on circuits and systems for video technology* **19**(6), 900–905 (2009)
12. Athimethphat, M., Patanavijit, V.: A non-linear illuminations balancing for reconstructed degraded scanned text-photo image. In: 2010 10th International Symposium on Communications and Information Technologies, pp. 1158–1163 (2010). IEEE
13. Meng, G., Xiang, S., Zheng, N., Pan, C.: Nonparametric illumination correction for scanned document images via convex hulls. *IEEE transactions on pattern analysis and machine intelligence* **35**(7), 1730–1743 (2012)

14. Silling, S.A., Lehoucq, R.: Peridynamic theory of solid mechanics. In: *Advances in Applied Mechanics* vol. 44, pp. 73–168. Elsevier, ??? (2010)
15. Di Paola, M., Failla, G., Zingales, M.: Physically-based approach to the mechanics of strong non-local linear elasticity theory. *Journal of Elasticity* **97**(2), 103–130 (2009)
16. Rosasco, L., Belkin, M., Vito, E.D.: On learning with integral operators. *Journal of Machine Learning Research* **11**(Feb), 905–934 (2010)
17. Fife, P.: Some nonclassical trends in parabolic and parabolic-like evolutions. In: *Trends in Nonlinear Analysis*, pp. 153–191. Springer, ??? (2003)
18. Land, E.H., McCann, J.J.: Lightness and retinex theory. *Josa* **61**(1), 1–11 (1971)
19. Bella, F.Z.A., El Rhabi, M., Hakim, A., Laghrib, A.: Reduction of the non-uniform illumination using nonlocal variational models for document image analysis. *Journal of the Franklin Institute* **355**(16), 8225–8244 (2018)
20. Crandall, M.G., Ishii, H., Lions, P.-L.: User’s guide to viscosity solutions of second order partial differential equations. *Bulletin of the American mathematical society* **27**(1), 1–67 (1992)
21. Ohnuma, M., Sato, K.: Singular degenerate parabolic equations with applications to the p-laplace diffusion equation. *Hokkaido University Preprint Series in Mathematics* **332**, 1–20 (1996)
22. Giga, Y.: *Surface Evolution Equations*. Springer, ??? (2006)

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Availability of data and materials

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Author’s contributions

All authors contributed equally to the production of this paper. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Figures

Typical results are shown in Figure 2 and Figure 3. For SRCR, it seems to have some difficulty enhancing image in underexposed and overexposed regions. The luminance addition in the darker regions is insufficient and unnatural color and halo artifacts are introduced which caused bigger Z_Std . For the original ALMF, it is easy to brighten overexposed regions losing information in highlight regions to have the "blowing out" artifact and enlarge the block effect. However, our method possesses more details with high visual quality in non-uniform lighting conditions than ALMF. Just as discussed in [6], the histogram shows the characteristics of the image, the visibility should be preserved before and after LR, Figure 4(d) shows that the shadow region in the original image shifts to the better luminance range, and the sky region almost unchanged, for more displayed results, the proposed method can restore local details and global contrast. Especially for these degraded images in format of .jpg, our method does not amplify the block effect badly. Besides the subjective evaluation, values of objective standards are listed in Table 1.

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(d)

Figure 1

Images enhancement results: (a) Original degraded image, (b) Recovered reflectance by the proposed nonlocal model (4) with $p=2$, (c) Recovered reflectance by the proposed nonlocal model (4), (d) Recovered reflectance by the proposed nonlocal model (16).

SRCCr, it seems to have some difficulty enhancing image in underexposed and overexposed regions. The luminance addition in the darker regions is insufficient and unnatural color and halo artifacts are introduced which caused bigger Z_Std . For the original ALMF, it is easy to brighten overall density losing information in highlight regions to have the "wiping out" artifact and enlarge the block effect. However, our method possesses more details with high visual quality in non-uniform lighting conditions than ALMF. Just as discussion [6], the histogram shows the characteristics of the image, the visibility should be preserved before and after LR, Figure (d) shows that the shadow region in the original image shifts to the better luminance range, and the sky region almost unchanged, for more displayed results, the proposed method can restore local details and global contrast. Especially for these degraded images in format of .jpg, our method does not amplify the block effect badly. Besides the subjective evaluation, values of objective standards are listed in Table 1.

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(d)

Figure 2

Images enhancement results: (a) Original degraded image, (b) Recovered reflectance by the proposed nonlocal model (4) with $p=2$, (c) Recovered reflectance by the proposed nonlocal model (4), (d) Recovered reflectance by the proposed nonlocal model (16).

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(d)

Figure 3

Images enhancement results: (a) Original degraded image, (b) Recovered reflectance by the proposed nonlocal model (4) with $p=2$, (c) Recovered reflectance by the proposed nonlocal model (4), (d) Recovered reflectance by the proposed nonlocal model (16).

Figure 4

Images enhancement results: (a) Original degraded images, (b) Recovered digits by the proposed nonlocal model (4), (c) Recovered digits by the proposed nonlocal model (16)

to give you a fair hearing and he wants you
not to make the changes suggested. Will
was proposing to change the wording a little
and try it again. Now he says that he

to give you a fair hearing and he wants you
not to make the changes suggested. Will
was proposing to change the wording a little
and try it again. Now he says that he

Telegram just recd from Albany
says "Hearing fixed for Wednesday
22nd." Have sent postal to Mrs
Blatch and shall depend upon
you two and I hope three
Mr. W. Chapman
160 Hicks St
2-18-99

Telegram just recd from Albany
says "Hearing fixed for Wednesday
22nd." Have sent postal to Mrs
Blatch and shall depend upon
you two and I hope three
Mr. W. Chapman
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There is such a charm in mystery,
that I shall not try to remove
the thin veil which surrounds
the origin of the glory
of golden daffodils which
graced the President's desk

There is such a charm in mystery,
that I shall not try to remove
the thin veil which surrounds
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(a)

(b)

Figure 5

Images enhancement results from H-DIBCO: (a) Original degraded images, (b) Recovered text by the proposed nonlocal model (16).