IET Image Processing

Research Article

Nighttime image enhancement using a new illumination boost algorithm

ISSN 1751-9659
Received on 1st December 2018
Revised 21st January 2019
Accepted on 18th March 2019
E-First on 29th May 2019
doi: 10.1049/iet-ipr.2018.6585
www.ietdl.org

Zohair Al-Ameen[1] ✉
[1]*Department of Computer Science, College of Computer Science and Mathematics, University of Mosul, Mosul, Nineveh, Iraq*
✉ *E-mail: qizohair@gmail.com*

Abstract: Nighttime images are often obtained with low brightness, deficient contrast, and latent colours. Thus, it is important to improve such aspects in order to obtain acceptable quality images. Hence, a new illumination boost algorithm is proposed in this study, in which it can improve the brightness, ameliorate contrast and process the colours of nighttime images properly. Accordingly, the proposed algorithm utilises only a small number of steps and uses several processing concepts to achieve the desired results. Intensive experiments and tests with various natural-degraded nighttime images are made to validate the performance of the proposed algorithm. In addition, it is compared with eight contemporary algorithms, and the obtained results from these comparisons are evaluated using two specialised image quality assessment metrics. Using the results of the achieved experiments and comparisons, it became evident that the proposed algorithm can provide satisfactory outcomes, in which it provided visually pleasing results and outperformed the comparison algorithms in terms of scored accuracy and visual quality.

1 Introduction

Modern computer vision and digital image processing applications require images with high visibility to achieve the designated tasks properly [1]. As known, the night environment is somewhat intricate as the light is insufficient for proper image acquisition [2]. In addition, most of the available digital cameras cannot capture acceptable quality nighttime images, in that the acquired images in a low-light environment are often degraded by several artefacts and have a low perceived quality [3]. Thus, it is highly required to improve the quality of such images to become suitable for further processing and interpretation [4]. The foremost aim of nighttime image enhancement is to recover acceptable quality images in terms of brightness, contrast, and colours without introducing any undesirable effects, so that the recovered images appear better and become more suitable for many existing image-related applications [5]. The illumination of nighttime images is characterised as non-uniform, wherein processing such images is deemed a challenge and a hot research field that is still open for research since many of the available enhancement algorithms produce results with unnatural appearances [6]. Thus, different inspiring research works have been conducted by various specialists to address this problem in order to provide new algorithms that have better processing abilities and are able to produce improved results.

Accordingly, Fu *et al*. [7] proposed a bright channel prior (BCP) based algorithm that utilises the BCP and the retinex model to remove the colour distortions, over-enhancement, and halo effects produced by the traditional model. This algorithm starts by applying a specific filtering process to obtain the bright channel of the image. Then, a quadratic function is applied to obtain the global minimum. Next, the output is further refined using a specialised function. Finally, the results are corrected according to certain pre-detected priors. In addition, Wang *et al*. [8] provided a naturalness preserved enhancement (NPE) algorithm, which utilises the retinex model and works by applying a bright-pass filter to disintegrate the input image into illumination and reflectance which are used later to determine the naturalness and details of the image. Then, a bi-log transformation is used to remap the illumination in order to balance the naturalness and the details of the image. Moreover, an improved multi-scale retinex (IMSR) algorithm is developed in [9], in which the authors modified the algorithm by replacing the logarithmic function of the traditional multi-scale retinex (MSR) by an adapted sigmoid function to reduce the loss of image data. Then, the obtained results by the sigmoid-MSR method are combined with the original images to produce the final result.

Furthermore, a probabilistic image enhancement (PIE) based algorithm is introduced in [10], wherein it improves the processing abilities of the traditional retinex model by using a probabilistic concept to achieve a concurrent approximation of reflectance and illumination in the linear domain via the use of a maximum a posteriori (MAP) concept. Then, a characteristics analysis of the logarithmic transformation is attained to identify the approximation reliability of illumination and reflectance. Finally, the MAP concept is converted into an energy minimisation concept to disintegrate the illumination and reflectance properly, while an alternating direction method of multipliers is implemented to approximate the portions of reflectance and illumination concurrently. Besides, Ying *et al*. [11] provided a camera response model (CRM) based algorithm, which considers the effect of the camera response function in the enhancement process. This algorithm determines the proper CRM to compute the exposure ratio map (ERM) using the observed histogram characteristics. Then, the detected ERM is utilised to enhance the input image to produce the output image. In addition, Ren *et al*. [12] introduced a sequential decomposition (SD) based algorithm, in which it works by decomposing the retinex model into a consecutive sequence to approximate a reduced-noise reflectance and a piecewise illumination. Then, the illumination layer is adjusted using a specialised method, while the reflectance layer is denoised using spatial smoothing via weight matrices.

Likewise, Li *et al*. [13] proposed a robust retinex model (RRM) based algorithm, which uses the retinex model to modify the approximated reflectance and illumination and takes into consideration the noise map of a given image to obtain the enhanced image. In this work, the authors developed an optimisation function that involves new regularisation aspects for reflectance and illumination. Specifically, the L1 norm is used to limit the smoothness of the illumination layer, an adopted fidelity term is used for the reflectance layer to reveal more structural details, and a specialised method is used to estimate the noise of the retinex model. As well, this algorithm utilises an augmented Lagrange multiplier with no logarithmic operations to solve the optimisation problem in a proper manner. Finally, Tanaka *et al*. [14] proposed a gradient-based enhancement (GBE) algorithm, which works by converting the input image to the luminance–chrominance colour space. Then, the gradients of the luminance component are extracted and processed by a specially designed method to increase the apparent details of the dark regions. Next, an optional gradient filtering process is applied to improve the overall appearance of the details. To produce the resulting image, an image integration procedure with the intensity-range constraint is applied. As seen from the reviewed algorithms, many of such utilise the retinex model to improve the low-visibility phenomenon of digital images. However, various retinex-based algorithms can introduce unwanted effects such as halo artefact, improper contrast, washed-out colours, and extra smoothness to the processed images. In addition, some of the retinex-based algorithms can include excessive calculations to produce the final image. Therefore, developing a low-complexity algorithm that utilises a small number of calculations to produce effects-free and high-quality images is extremely desirable.

Hence, a new illumination boost algorithm is proposed in this study, in which it uses a small number of steps and utilises several processing concepts to produce effect-free results rapidly that have a high perceived quality and no visible flaws. Accordingly, the main purpose of the proposed algorithm is to preserve the brightness in the bright areas from being extremely amplified while boosting the brightness in the dark areas so that the latent image details appear properly and as a result, the resulting images have a better-perceived quality. It works by applying specialised logarithmic and exponential functions to boost the low- and mid-intensities, enhance the local contrast, and process the high-intensities in a proper manner. Then, the resulting images from these two functions are combined together using an adapted logarithmic image processing (LIP) method to obtain an image that holds the characteristics of both images. Next, a modified S-curve function is used to improve the overall brightness of the image. Finally, a linear scaling function is applied to redistribute the intensities of the image to the standard dynamic range. The proposed algorithm is tested with various natural-degraded nighttime images which are collected from various internet websites. Moreover, it is compared with eight algorithms and the accuracy of the obtained results is measured using two advanced and specialised image quality assessment (IQA) metrics. The outcome of the conducted experiments and comparisons revealed the efficiency of the proposed algorithm as it outperformed the comparison algorithms in different aspects. The rest of this article is organised as follows: the proposed algorithm is fully described in Section 2, while the achieved experiments and comparisons along with their discussions are stated in Section 3. Finally, some vital concluding statements are given in Section 4.

2 Proposed illumination boost algorithm

The main aim of the proposed algorithm is to recover acceptable quality results from various degraded nighttime images which are characterised by uneven illumination distribution and overall dark appearance. In general, the proposed algorithm improves the local contrast, enhances the low- and mid-intensity pixels while preserving the high-intensity pixels from being extremely incremented. When these two traits are handled properly, the colours eventually appear in a better way. The proposed algorithm provides the desirable results by utilising different processing concepts. Accordingly, it starts by processing the input image by a logarithmic scaling function. This function is used to estimate the transformation achieved by the retina of the human visual system [15]. Moreover, it can be used to enhance the low- and mid-intensities while preserving the high-intensities from extreme increment. This function is computed using the following equation [15]:

$$I_1 = \frac{\max(X)}{\log(\max(X) + 1)} * \log(X + 1), \tag{1}$$

where X is the input colour image, I_1 is the resulting image from the logarithmic scaling function, and * is a multiplication operator. Next, the input image X is processed again by a non-complex exponential function to modify the local contrast and attenuate the high-intensities of the input image. This function is calculated using the following equation [16]:

$$I_2 = 1 - \exp(-X), \tag{2}$$

where I_2 is the resulting image from the used exponential function. Afterwards, images I_1 and I_2 are combined together using a proper LIP model. Accordingly, different LIP models exist to combine the characteristics of two digital images. However, one of the mentioned LIP models in [17] can provide promising results when tested with various nighttime images. The used LIP model can be computed as follows [17]:

$$I_3 = \frac{I_1 + I_2}{1 + (I_1 * I_2)}. \tag{3}$$

To reach the best performance using the above LIP model, it is adapted to fit the nature of the used images. The utilised LIP model in this algorithm is computed using the following equation:

$$I_3 = \frac{I_1 + I_2}{\lambda + (I_1 * I_2)}, \tag{4}$$

where, λ is a scalar that controls the enhancement process, in which it is added to avoid the generation of unsuitable pixel values. At this point, image I_3 holds the characteristics of both images I_1 and I_2. Despite that, the overall brightness of image I_3 is low and thus, further enhancement is required so that, most of the latent image details appear properly. Hence, a modified cumulative distribution function of hyperbolic secant distribution (CDF-HSD) is used to improve the overall brightness. The standard HSD is a well-known function in the fields of probability and statistics. The CDF of this method is one type of S-curve functions that can be used to adjust the brightness and contrast. The standard CDF-HSD is computed using the following equation [18]:

$$F = \frac{2}{\pi} * \arctan(\exp(w)). \tag{5}$$

To get the best performance out of this function, it is modified to increase its competence in improving the brightness of dark image regions. The newly modified CDF-HSD is calculated as follows:

$$I_4 = \mathrm{erf}(\lambda * \arctan(\exp(I_3)) - 0.5 * I_3), \tag{6}$$

where I_4 is the resulting image from the modified CDF-HSD equation. The performed modifications helped noticeably in increasing the function's processing efficiency in terms of brightness enhancement. First, the error function (erf) is added to increase the curvy transformation of the CDF-HSD equation, which is highly beneficial in increasing the brightness of the dark image regions. Moreover, the value of $\pi/2$ is replaced by λ to control the amount of enhancement, in which it should fulfil $2 \leq \lambda \leq 7$, where a higher value leads to more brightness in the output image. In addition, subtracting the value of $0.5 \times I_3$ helped in regularising the image tonality so that it appears very much similar to the observed scene. Despite that, the pixels distribution of image I_4 remains limited to a specific dynamic range, and the resulting image from this step appears very white. Hence, a normalisation function is applied to linearly scale the pixels values to fit the standard range. The used normalisation function is computed as follows [19]:

$$I_5 = \frac{I_4 - \min(I_4)}{\max(I_4) - \min(I_4)}, \tag{7}$$

where I_5 is the final result of the proposed algorithm. To better comprehend the flow and operations specifics of the proposed algorithm, an abridged pseudo-code is provided below. Moreover, Figs. 1 and 2 are added to demonstrate the output of the proposed algorithm for each step along with the corresponding histogram for

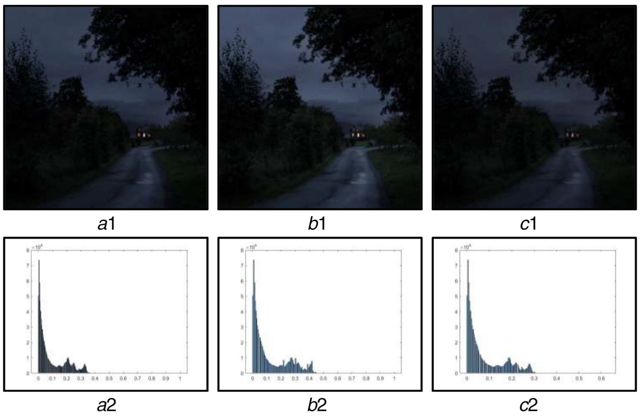

Fig. 1 *Step by step execution for the proposed algorithm using a natural-degraded nighttime image with λ = 4* ***(part 1)****:* ***(a1)*** *Natural-degraded image;* ***(b1)*** *The output of (1);* ***(c1)*** *The output of (2);* ***(a2)–(c2)*** *Are the histograms of images* ***(a1)–(c1)***

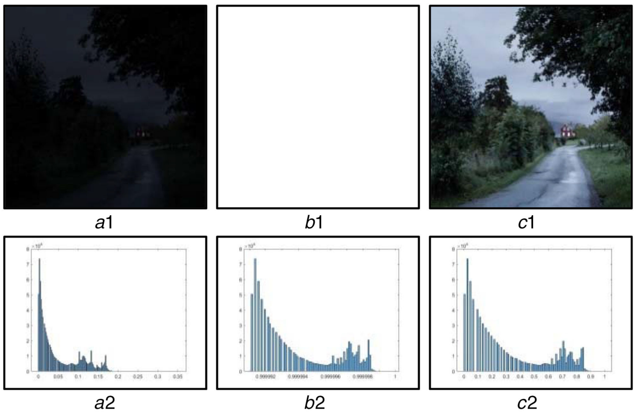

Fig. 2 *Step by step execution for the proposed algorithm using a natural-degraded nighttime image with λ = 4* ***(part 2)****:* ***(a1)*** *The output of (4);* ***(b1)*** *The output of (6);* ***(c1)*** *The output of (7);* ***(a2)–(c2)*** *Are the histograms of images* ***(a1)–(c1)***

Input: nighttime image X, parameter λ
Calculate the logarithmic scaling function using equation (1)
Calculate the non-complex exponential function using equation (2)
Apply the adapted LIP model using equation (4)
Compute the modified CDF-HSD function using equation (6)
Compute the normalization function using equation (7)
Output: improved image I_5

Fig. 3 *Pseudo-code of the proposed illumination boost algorithm*

each output. To end with, the proposed algorithm has many advantages such as low-calculations utilisation, rapid implementation, simple structure, and fine-quality results. Such traits can make this algorithm desirable to be utilised with applications that require real-time processing. In addition, it can be used with various imaging systems that have limited hardware and aim to deliver acceptable results (Fig. 3).

3 Results and discussion

In this part of the study, the obtained results are demonstrated along with their discussions by performing various experiments and comparisons. This is made to truly appraise the performance abilities of the proposed algorithm in processing different natural-degraded nighttime images. The proposed algorithm is compared with eight contemporary algorithms of BCP, NPE, IMSR, PIE, CRM, SD, RRM, and GBE [7–14]. Furthermore, the obtained results from these comparisons are evaluated using two advanced IQA metrics of lightness order error (LOE) [8] and blind image quality measure of enhanced images (BIQME) [20]. The LOE is a reduced-reference metric that is used to measure the error of the lightness order between the resulting image and its degraded

Fig. 4 *Results of processing various natural-degraded images by the proposed algorithm*
(a1)–(c1) Are natural-degraded nighttime images, ***(a2)–(c2)*** Are images processed by the proposed algorithm with λ values of (5, 3, 3.2)

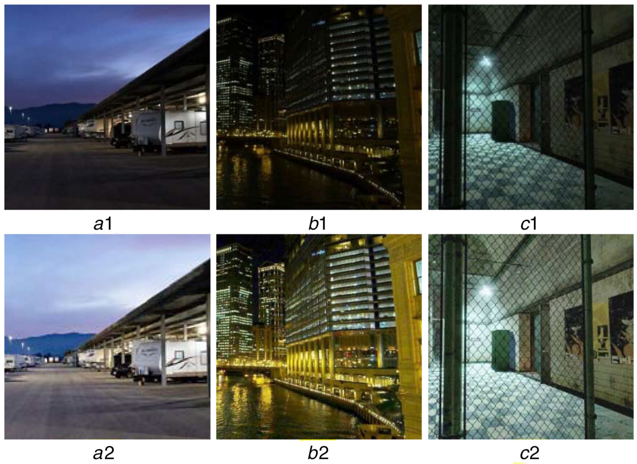

Fig. 5 *Results of processing various natural-degraded images by the proposed algorithm*
(a1)–(c1) Are natural-degraded nighttime images, ***(a2)–(c2)*** Are images processed by the proposed algorithm with λ values of (2.25, 3.5, 2)

counterpart. As known, the relative order of lightness signifies the lightness variation and the source direction of light. Accordingly, the relative order of lightness is related to the naturalness of an improved image in various local regions. The output of the LOE metric is a numerical value, in which a lower value signifies a better quality result.

On the other hand, BIQME is a no-reference metric that determines the quality of a given image based on many features including, brightness, contrast, naturalness, and colourfulness. In this context, a good quality image should have adequate brightness, natural contrast, and vivid colours, so that the image details appear properly and are perceived accurately by the viewer. Thus, the adjusted entropy, the log, and contrast energies are utilised for the contrast feature. Moreover, the characteristics of the dynamic range are used for the brightness and colourfulness features. In addition, the traditional natural scene statistics and the dark channel prior concepts are employed for the naturalness feature. The output of the BIQME metric is a numerical value, in which a higher value signifies a better quality result. Regarding the computer specifications, all experiments and evaluations are achieved using MATLAB 2017a with a 16 GB memory and a 2.8 GHz Core I7-7700HQ processor. Figs. 4–8 demonstrate the results of processing various natural-degraded nighttime images by the proposed algorithm using different λ values. Figs. 9–14 display the results of the conducted comparisons using natural-degraded nighttime images.

Fig. 6 *Results of processing various natural-degraded images by the proposed algorithm*
(a1)–(c1) Are natural-degraded nighttime images, ***(a2)–(c2)*** Are images processed by the proposed algorithm with λ values of (5, 4, 3.8)

Fig. 7 *Results of processing various natural-degraded images by the proposed algorithm*
(a1)–(c1) Are natural-degraded nighttime images, ***(a2)–(c2)*** Are images processed by the proposed algorithm with λ values of (3.1, 4.5, 4.8)

Fig. 8 *Results of processing various natural-degraded images by the proposed algorithm*
(a1)–(c1) Are natural-degraded nighttime images, ***(a2)–(c2)*** Are images processed by the proposed algorithm with λ values of (3.3, 3.8, 3.6)

Fig. 9 *Comparison results of the proposed and the compared algorithms (part 1)*
(a) Natural-degraded image; images from ***(b)–(f)*** Are processed by: ***(b)*** BCP [7], ***(c)*** NPE [8], ***(d)*** IMSR [9], ***(e)*** PIE [10], ***(f)*** proposed algorithm

Fig. 10 *Comparison results of the proposed and the compared algorithms (part 2)*
(a) Natural-degraded image; images from ***(b)–(f)*** Are processed by: ***(b)*** CRM [11], ***(c)*** SD [12], ***(d)*** RRM [13], ***(e)*** GBE [14], ***(f)*** proposed algorithm

Tables 1–3 exhibit the scored accuracies by the used IQA metrics and the implementation times of the proposed and the compared algorithms. Fig. 15 illustrates the analytical graphs of the average performances detailed in Tables 1–3. From the obtained results that are displayed in Figs. 4–8, it is evident that the proposed algorithm is successful in processing various natural-degraded nighttime images. The obtained results have acceptable appearances, the dark areas of the images appear in a more appropriate way, the bright parts of the images are preserved from extreme amplification, the colours are natural, and the contrast is adequate. In addition, no visible defects are observed on the results that looked more realistic to the observer. This is significant because such satisfactory results are obtained by an algorithm that utilises a few non-complex operations.

When the degraded image is compared to its enhanced counterpart, it looks as if a custom bright layer is added to the dark areas while considering the bright areas of the image from extreme increment and allowing proper colours lucidity. The quality of the processed images is enhanced remarkably when a suitable λ value is utilised. Accordingly, it is obvious that different λ values have been utilised. The reason being every image varies from other images in terms of brightness, contrast, colours, and resolution. Still, the proposed algorithm managed to produce promising outcomes without introducing any unpleasant effects.

From the obtained comparison results that are displayed in Figs. 9–15 and Tables 1–3, it is clear that different performances were recorded due to variations in the utilised processing concepts. All the comparison algorithms were able to improve the visibility of the latent image details. However, several remarks were recorded regarding their performances, as some of these algorithms introduced certain undesirable effects, or were unsuccessful in providing proper processing for some important image features including the brightness, contrast, colours, or sharpness. As for the BCP algorithm, it introduced a glowing effect around the edges and boundaries of the recovered images. Also, it provided an unnatural brightness with dark colours for some of the recovered images.

Fig. 11 *Comparison results of the proposed and the compared algorithms (part 1)*
(a) Natural-degraded image; images from ***(b)–(f)*** are processed by: ***(b)*** BCP [7], ***(c)*** NPE [8], ***(d)*** IMSR [9], ***(e)*** PIE [10], ***(f)*** proposed algorithm

Fig. 12 *Comparison results of the proposed and the compared algorithms (part 2)*
(a) Natural-degraded image; images from ***(b)–(f)*** Are processed by: ***(b)*** CRM [11], ***(c)*** SD [12], ***(d)*** RRM [13], ***(e)*** GBE [14], ***(f)*** proposed algorithm

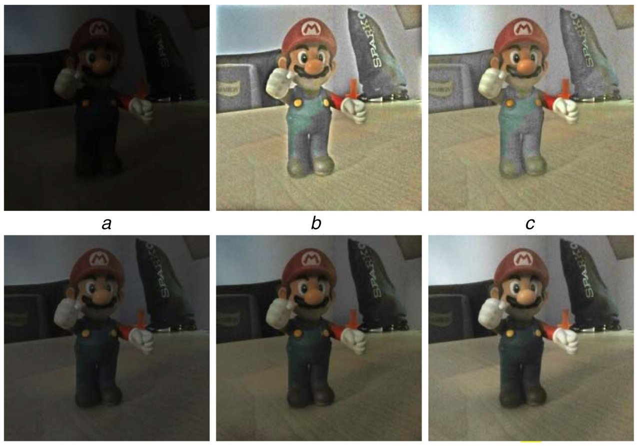

Fig. 13 *Comparison results of the proposed and the compared algorithms (part 1)*
(a) Natural-degraded image; images from ***(b)–(f)*** Are processed by: ***(b)*** BCP [7], ***(c)*** NPE [8], ***(d)*** IMSR [9], ***(e)*** PIE [10], ***(f)*** proposed algorithm

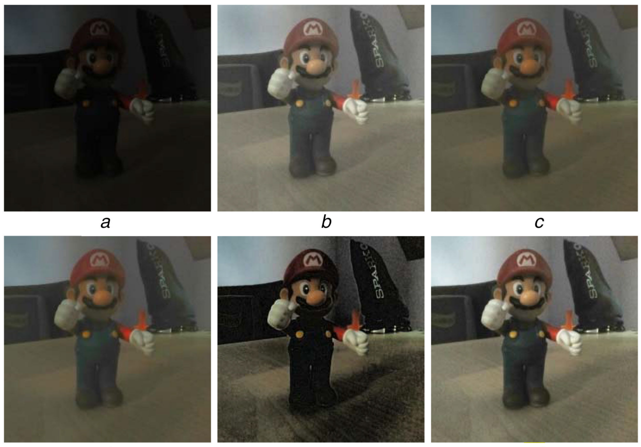

Fig. 14 *Comparison results of the proposed and the compared algorithms (part 2)*
(a) Natural-degraded image; images from ***(b)–(f)*** Are processed by: ***(b)*** CRM [11], ***(c)*** SD [12], ***(d)*** RRM [13], ***(e)*** GBE [14], ***(f)*** proposed algorithm

Table 1 Scored accuracies by the proposed and the compared algorithms using the LOE metric

#	Methods	Image 1 – road	Image 2 – house	Image 3 – mario	Averages
1	BCP [7]	708.9545	1170.60	821.9212	900.492
2	NPE [8]	788.7749	275.5032	358.4772	474.252
3	IMSR [9]	191.1353	101.8784	184.0256	159.013
4	PIE [10]	231.1882	109.2744	157.6232	166.029
5	CRM [11]	176.9120	237.0252	92.6000	168.846
6	SD [12]	182.3456	135.0960	160.6132	159.352
7	RRM [13]	179.5572	135.0468	161.0472	158.55
8	GBE [14]	526.7023	674.0868	220.5556	473.782
9	proposed algorithm	**154.2618**	**64.2404**	**77.9672**	**98.823**

Therefore, it scored the lowest according to LOE, somewhat well according to BIQME and moderate implementation times.

As for the NPE algorithm, it introduced a halo effect in some regions of the recovered images. In addition, it provided a sufficient contrast, yet it over-enhanced the brightness in certain situations, while the image noise appeared in a distorted form. Therefore, it scored quite low according to LOE, moderate according to BIQME, and provided practically high implementation times. As for the IMSR, it provided moderate enhancement in terms of brightness, delivered slightly faded colours with insufficient contrast, and the resulting images appeared relatively dark. That's why it scored moderately according to LOE, the lowest according to BIQME, yet provided very low implementation times. As for the PIE algorithm, it delivered reasonable outcomes in terms of contrast, sharpness, and colours. However, the overall brightness of the image remains deficient as it scored moderately according to LOE, somewhat low according to BIQME, and provided reasonable implementation times.

As for the CRM, it provided different performances for the used images, since some images appeared with insufficient contrast and others appeared with slightly faded colours. That's why it scored relatively moderate according to LOE and BIQME with quite low implementation times. As for the SD and RRM algorithms, they provided very much similar performances slightly in favour of the

Table 2 Scored accuracies by the proposed and the compared algorithms using the BIQME metric

#	Methods	Image 1 – road	Image 2 – house	Image 3 – mario	Averages
1	BCP [7]	0.5842	0.6378	0.4600	0.56067
2	NPE [8]	0.5103	0.6397	0.4420	0.53067
3	IMSR [9]	0.4002	0.5733	0.3640	0.44583
4	PIE [10]	0.4646	0.5987	0.4302	0.49783
5	CRM [11]	0.4811	0.5952	0.4638	0.51337
6	SD [12]	0.5709	0.6405	0.4672	0.55953
7	RRM [13]	0.5666	0.6441	0.4641	0.55827
8	GBE [14]	0.5029	0.6079	0.4734	0.52807
9	proposed algorithm	**0.6190**	**0.6501**	**0.5407**	**0.6032**

Table 3 Implementation times (in seconds) for the proposed and the compared algorithms

#	Methods	Image 1 – road	Image 2 – house	Image 3 – mario	Averages
1	BCP [7]	0.835073	3.429616	1.979924	2.08154
2	NPE [8]	4.287158	29.262321	16.865011	16.8048
3	IMSR [9]	0.373012	0.535737	0.472461	0.4604
4	PIE [10]	0.473247	2.777769	1.089989	1.447
5	CRM [11]	0.250001	0.866076	0.588924	0.56833
6	SD [12]	1.842862	16.979012	8.577823	9.13323
7	RRM [13]	5.594993	63.359220	20.756273	29.9035
8	GBE [14]	0.674135	6.461845	2.115854	3.08394
9	proposed algorithm	**0.020426**	**0.132848**	**0.077053**	**0.076775**

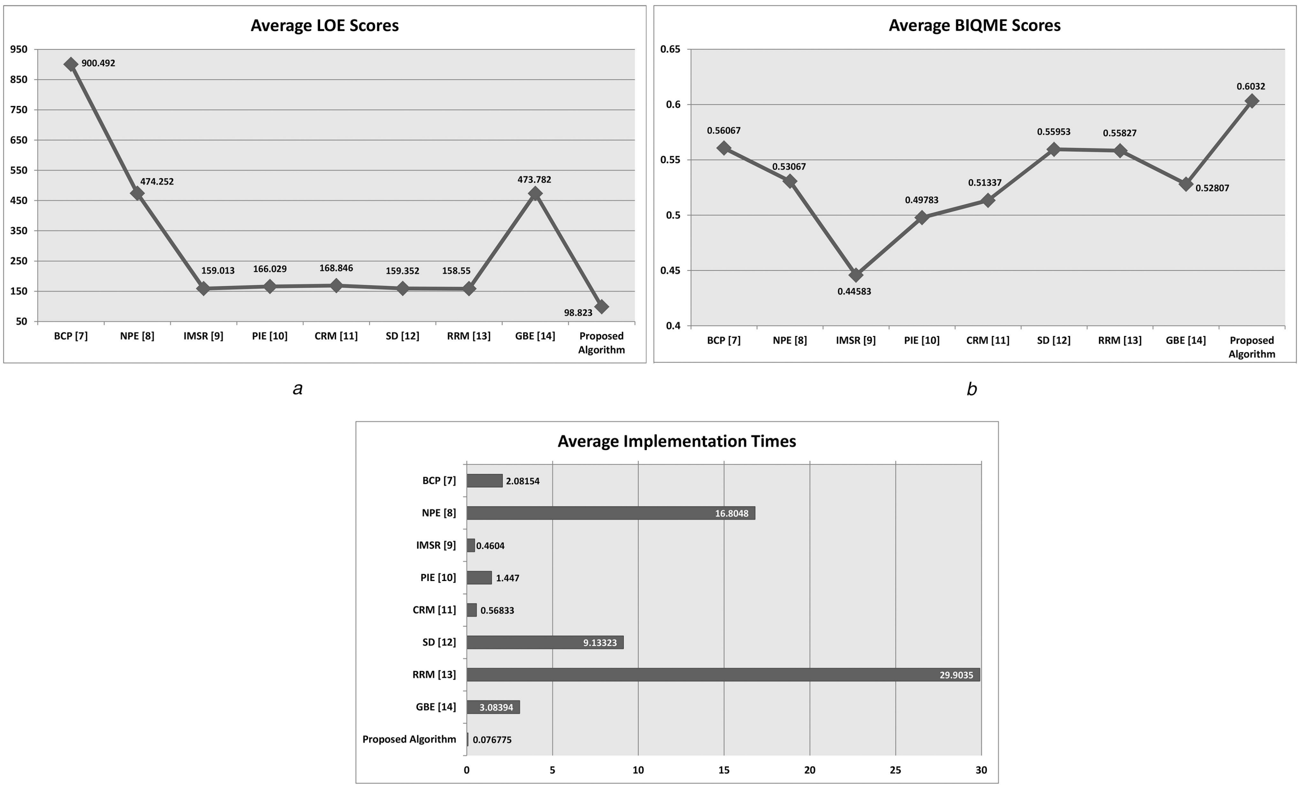

Fig. 15 *Analytical graphs of the average recorded performances*
(a) LOE metric, ***(b)*** BIQME metric, ***(c)*** Implementation times

SD algorithm. Both algorithms introduced extra smoothness and insufficient brightness to the processed image.

Still, they delivered rich colours with relatively adequate contrast. Accordingly, their performances are somewhat similar to IMSR according to LOE and are very much similar to BCP according to BIQME. Regarding the implementation times, the RRM provided the highest implementation time while the SD performed much faster. As for the GBE algorithm, it introduced a glowing effect around the recovered edges which is somewhat similar to the effect of the BCP algorithm. Moreover, it delivered an abnormal brightness and shady colours for the recovered images. Therefore, it performed poorly according to LOE and BIQME and provided moderate implementation times.

As for the proposed algorithm, it compared favourably and outperformed the comparison algorithms in terms of scored accuracy, perceived quality, and implementation time. Accordingly, the resulting images from the proposed algorithm appear with natural brightness, adequate contrast, proper colours, and acceptable overall illumination, as well as, no noticeable flaws were observed on the resulting images. Regarding the implementation times, the proposed algorithm was the fastest among the compared algorithms. This is an important matter because such satisfactory results are obtained using a low-complexity algorithm that involves a small number of calculations.

As mentioned earlier, the proposed algorithm has many advantages. Despite that, it has one shortcoming that is the value of λ must be chosen manually by the operator. For future development, a suitable optimisation technique can be developed and used to determine the optimum value of λ in an automatic way. In this era of modern computing, developing a low-complexity algorithm that can deliver high-quality results rapidly is a tedious and challenging task. However, such a task is evidently achieved by providing a new algorithm that has a low-computation cost. Thus, it is expected to extend the application of this algorithm to many real-life applications especially those that capture and process images in low-light environments.

4 Conclusion

A new illumination boost algorithm is proposed in this study for nighttime image enhancement. The newly developed algorithm involves the application of simple logarithmic and exponential functions, an adapted LIP method, a modified CDF-HSD function, and a linear scaling function. To assess the performance abilities of the proposed algorithm, it is tested with different natural-degraded nighttime images, it is compared with eight specialised algorithms, and the output of these comparisons is evaluated in terms of two advanced IQA metrics and implementation times. As a consequence, the proposed algorithm provided visually pleasing results with no visible flaws and outperformed the compared algorithms in terms of implementation time, scored accuracy, and perceived quality. Finally, the proposed algorithm can be adapted to be used in improving nighttime images that are produced by various imaging devices specifically those relative to real-time or own limited hardware specifications.

5 Acknowledgments

The author is grateful to the editors and reviewers for their constructive comments. In addition, the author declares that there is no conflict of interest involved in this study. Moreover, the author declares that this research did not receive any kind of funding.

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