Low-Light Video Enhancement Based on Optimal Gamma Correction Parameter Estimation

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***Abstract*—We propose an efficient low-light video enhancement algorithm based on optimal gamma correction parameter estimation. We first divide the dynamic range into dark range and bright range, and formulate a convex optimization problem for each range. By efficiently solving the optimization problems, we obtain the optimal gamma parameter, and then yield the result images. In Addition, we extend the proposed algorithm to video enhancement by sustaining the temporal coherency. Experimental results demonstrate that the proposed algorithm achieves higher enhancement performance than conventional algorithms, while providing substantial improvement in speed.**

***Keywords*—Low-light image enhancement, gamma correction, image restoration**

I. INTRODUCTION

The recent advancements in digital imaging have made it possible to acquire high-quality images using various kinds of capturing devices. However, acquired images and videos captured in low-light environment exhibit degraded quality caused by low dynamic ranges. These low-quality images and videos degrade the performance of subsequent image processing and computer vision applications, including surveillance, object detection, and segmentation. Hence, contrast enhancement algorithms have been researched to improve the quality of such captured images and videos [1-6]. In particular, the gamma correction technique has been employed in many contrast enhancement algorithms due to its simplicity and efficacy [1, 4, 6].

The gamma correction technique obtains the output pixel value y given the input pixel value x using the power function with γ as

$$y = M\left(\frac{x}{M}\right)^{\gamma} \quad (1)$$

where M denotes the maximum pixel value. Recent gamma correction-based contrast enhancement researches have focused on determining the optimal parameter γ to maximize the image quality. For example, in [1], Yang *et al.* proposed an effective algorithm that exploits the median value to determine the optimal gamma parameter. However, as the median function is nonlinear, the optimal parameter is obtained iteratively, making it inefficient. Thus, its computational complexity is too high to be employed in practical applications.

In this work, we develop an efficient low-light video enhancement algorithm based on the optimal gamma parameter estimation. Specifically, we formulate the gamma parameter estimation as a convex optimization problem with a quadratic cost function. Then, by solving the convex optimization problem via a closed-form solution, we obtain the optimal gamma parameter efficiently. In addition, we extend the parameter estimation to videos to preserve the temporal coherency in the video sequences. Experimental results demonstrate that the proposed algorithm provides higher-quality images and videos than the state-of-the-art algorithms, while requiring significantly lower computational complexities.

II. PROPOSED ALGORITHM

A. Optimal Gamma Correction Parameter Estimation

We estimate the optimal parameters for bright and dark regions independently by considering the statistical properties of the input images inspired by the recent work in [1]. Specifically, the optimal gamma parameter equalizes the average and standard deviation of luminance intensities in each range. More specifically, let $\mathbf{S}_{\text{dark}}$ denote the vector of pixel values in the dark range and N be the number of pixels in the dark range. Then, we formulate an optimization problem that obtains the optimal gamma value, given by

$$\begin{aligned} &\underset{\gamma}{\text{minimize}} && \left(\frac{1}{N}\mathbf{1}^T\mathbf{S}_{\text{dark}}^{\gamma} - M_L\right)^2 \\ &\text{subject to} && 0 \leq \gamma \leq 1 \end{aligned} \quad (2)$$

where M_L denotes the standard deviation of pixel values in the dark range. Note that the cost function in (1) is convex, since it is an exponential function, and the constraint is also convex. Therefore, the optimization problem in (1) is a convex optimization problem, which can be effectively solved using the Karush-Kuhn-Tucker (KKT) conditions. In this work, we obtain the optimal solution using Newton's method, since the cost function is differentiable. We repeatedly update the solution until the error between the successive values is less than 10^{-7}.

We obtain the optimal γ value for the bright range in a similar manner. For the bright range of pixels, the optimal gamma value must satisfy the constraint $1 \leq \gamma \leq 10$. Then, each optimal gamma value is used to transform the input pixel values to the output pixel values via (1).

B. Adaptive Color Restoration

The color image is obtained from the gamma-corrected luminance image by

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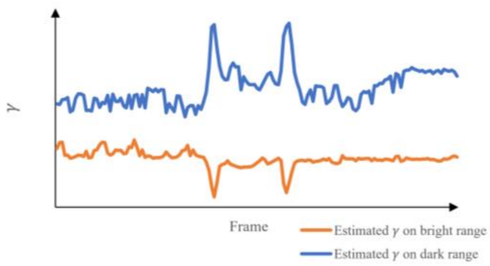
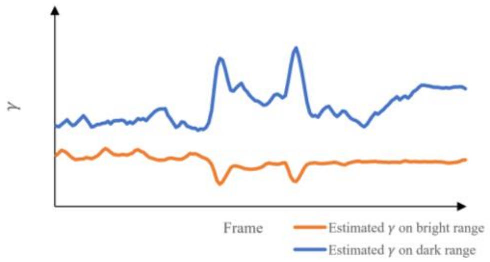


(a)



(b)

Fig. 2. Comparison of the γ parameter deviation for (a) frame-based approach and (b) the proposed algorithm.

$$I_{out}^{c}(x,y) = L_{out}(x,y)\left(\frac{I_{in}^{c}(x,y)}{L_{in}(x,y)}\right)^{s(x,y)} \tag{3}$$

where $s(x,y) = 1 - \tanh(L_b(x,y))$ denotes the saturation, and $c \in \{R,G,B\}$. Also, L_{out}, L_{in}, and I_{in}^{c} are the gamma-corrected pixel value, input pixel value, and input color value of each color channel, respectively.

C. Extension to Videos

The proposed image enhancement algorithm in the previous section may be applied to each frame of a video straightforwardly. However, in such a case, severe flickering artifacts would appear, because the temporal coherency between the frames is broken. Therefore, we must develop an effective video enhancement algorithm that preserves the temporal coherency to obtain high-quality videos. In this work, we obtain the optimal parameter γ_n of the current frame n from those of previous frames as

$$\gamma_n = \sum_{t=n-N}^{n} \alpha_t \gamma_t \tag{5}$$

where α_t is the weight of the tth frame which is given by

$$a_t = \frac{\exp\left[-\frac{(t-n)^2}{\sigma^2}\right]}{\sum_{k=n-N}^{n} \exp\left[-\frac{(k-n)^2}{\sigma^2}\right]}. \tag{6}$$

In (5) and (6), the number of frames used is fixed as $N = 4$, and we set $\sigma = 4$.

III. Experimental Results

We evaluate the performance of the proposed low-light video enhancement algorithm with those of Yang *et al.*'s algorithm [1], Lim *et al.*'s algorithm [2], and Rivera *et al.*'s algorithm [5].

TABLE I. Computation Times in Seconds of Yang *et al.*'s Algorithm [1], Lim *et al.*'s Algorithm [2], Rivera *et al.*'s Algorithm [5], and the Proposed Algorithm for the Test Images.

	Yang *et al.*	**Lim *et al.***	**Rivera *et al.***	**Proposed**
Street	2.14	11.2	0.33	0.08
Wheelchair	2.94	12.8	0.35	0.09
Checkerboard	2.76	12.1	0.34	0.08

Fig. 1 compares the enhanced results of the real-world images *Street*, *Wheelchair*, and *Checkerboard* in Fig. 1(a) [1]. Rivera *et al.*'s algorithm in Fig. 1(b) fails to effectively enhance the contrast in the dark regions. Yang *et al.*'s algorithm in Fig. 1(c) enhances the contrast but provides over-saturation artifacts. In Fig. 1(d), Lim *et al.*'s algorithm effectively enhances the contrast but yields blurring artifacts. On the contrary, the proposed algorithm provides higher-quality results than the conventional algorithms.

Fig. 2 shows the γ parameter variations for the dark and bright ranges. We observe that the proposed algorithm yields significantly lower deviations in the γ parameter compared to the frame-based approach that estimates the parameter independently for each frame. Thus, the proposed algorithm effectively alleviates the flickering artifacts.

Finally, Table I compares the actual execution times to process the images in Fig. 1. We use a PC with a 3.3 GHz CPU and 16 GB RAM. We observe that the proposed algorithm exhibits the highest efficiency.

IV. Conclusions

We proposed an effective gamma correction-based contrast enhancement algorithm for low-light images via optimal parameter estimation. The proposed algorithm first divides the input image into dark and bright ranges, and then formulates a convex optimization problem to obtain the optimal parameter. By efficiently solving the optimization problem, we obtained the enhanced results. In addition, we extended the algorithm to enhance videos by preserving the temporal coherency. Experimental results demonstrated that the proposed algorithm is capable of enhancing low-light images and videos with significantly lower computational complexities.

References

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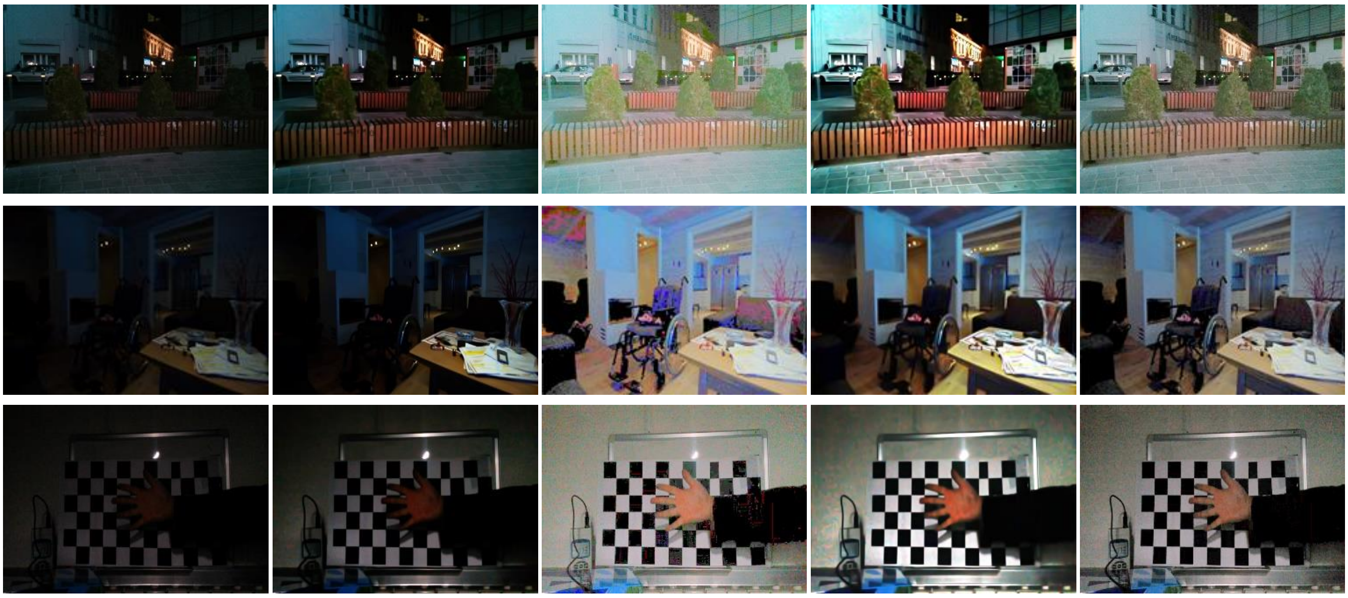

(a) (b) (c) (d) (e)

Fig. 1. Comparison of low-light image enhancement results. From top to bottom, *Street*, *Wheelchair*, and *Checkerboard*. The input images in (a) are enhanced by (b) Rivera *et al.*'s algorithm [5], (c) Yang *et al.*'s algorithm [1], (d) Lim *et al.*'s algorithm [2], and (e) the proposed algorithm.