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Adaptive Enhancement of Low-light Video Images Algorithm Based on Visual Perception

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시각 감지 기반의 저조도 영상 이미지 적응 보상 증진 알고리즘

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Abstract Aiming at the problem of low contrast and difficult to recognize video images in low-light environment, we propose an adaptive contrast compensation enhancement algorithm based on human visual perception. First of all, the video image characteristic factors in low-light environment are extracted: AL (average luminance), ABWF (average bandwidth factor), and the mathematical model of human visual CRC(contrast resolution compensation) is established according to the difference of the original image's grayscale/chromaticity level, and the proportion of the three primary colors of the true color is compensated by the integral, respectively. Then, when the degree of compensation is lower than the bright vision precisely distinguishable difference, the compensation threshold is set to linearly compensate the bright vision to the full bandwidth. Finally, the automatic optimization model of the compensation ratio coefficient is established by combining the subjective image quality evaluation and the image characteristic factor. The experimental test results show that the video image adaptive enhancement algorithm has good enhancement effect, good real-time performance, can effectively mine the dark vision information, and can be widely used in different scenes.

Key Words : visual perception; low-light; video images; contrast resolution; adaptive enhancement.

요 약 저조도 환경에서 영상 이미지의 콘트라스트가 낮고 식별이 어려운 문제를 목표로 사람의 시각 감지 기반의 콘트라스트 적응 보상 증진 알고리즘을 제안한다. 첫째, 저조도 환경에서 평균 밝기, 평균 대역폭 요인의 영상 이미지 특징 요인을 추출하고, 원본 영상의 회색/색도 차이에 따라 사람의 시각적 콘트라스트 해상도 보상의 수학적 모델을 설정하며, 실제 컬러의 3원색에 대해 각각 비례 적분하여 보상한다. 다음으로 보상 정도가 명시각 차이를 적절하게 구별할 수 있는 것보다 낮을 때 보상 임계값 선형 보상이 명시각에서 전체 대역폭으로 설정된다. 마지막으로 주관적인 이미지 품질 평가와 이미지 특성 요인을 결합하여 비례 계수를 보상하는 자동 최적화 모델을 구축한다. 실험 테스트 결과는 영상 이미지 적응 증진 알고리즘이 우수한 증진 효과와 우수한 실시간 성능을 가지며 다크 비전 정보를 효과적으로 마이닝할 수 있으며 다양한 시나리오에서 널리 사용될 수 있음을 보여준다.

주제어 : 시각 감지, 저조도, 영상 이미지, 콘트라스트 해상도, 적응 증진

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1. Introduction

Video images in low-light environments often have defects such as low contrast, low information, narrow grayscale/chromaticity spectral bandwidth, and weak sense of image hierarchy, which lead to difficulties in recognition by the human eye, so the research for low-light video image enhancement is of great practical significance [1].

Currently, the commonly used algorithms for low-light image enhancement are based on histogram equalization [2] and Retinex theory [3]. Histogram equalization improves the global contrast of the image, which is not applicable to the local enhancement of low-light video images, and is prone to color distortion when enhancing color images. Literature [4,5] proposed improved algorithms using histogram equalization, literature [6] proposed EFF(Exposure Fusion Framework) algorithm to obtain the optimal exposure ratio and enhance the image through exposure fusion, literature [7] proposed FEA(Fast Efficient algorithm) to invert the low-light video image, coupled with the de-fogging algorithm enhancement. This type of method is only effective for specific scene applications and has poor applicability.

Retinex theory based on the brightness and color perception of human vision extracts the target image components by separating the original illumination components, the traditional multi-scale Retinex algorithm [8] uses Gaussian blur to estimate the illumination components for the R, G, and B channels, which destroys the original color relationship and the color of the enhanced image is severely distorted. The LIME (Low-light image enhancement via illumination map estimation) algorithm proposed in literature [9] searches for the maximum value in the RGB three channels to estimate the illumination. The MF (Multi-scale Fusion) algorithm proposed in literature [10] estimates the illumination component based on morphological closure. The NPEA (Naturalness Preserved Enhancement Algorithm for Non-Uniform Illumination Images) algorithm proposed in literature [11] obtains the illumination component by means of luminance filter and double logarithmic transformation. Literature [12] replaces the three Gaussian filters in the traditional MSR (Multi-scale Retinex) algorithm with three guided-frequency filters to extract the illumination components, and improves the estimation of illumination components to improve the enhancement effect, but this type of algorithms introduces artifactual noise, which is not conducive to the mining of information of low-illumination images. Low illumination image enhancement based on deep learning [13], the complexity of the algorithm is high, and the real-time performance applied to video image enhancement processing is poor.

Aiming at the above problems, the algorithm in this paper is based on the human visual contrast resolution perception feature, sets the threshold compensation, enhances the low-light image without introducing artifacts, establishes the automatic optimization model of the compensation coefficients, and carries out the full-bandwidth optimization processing to realize the adaptive enhancement of the video image. Comparison of experimental results with related literature shows that the algorithm in this paper has better enhancement effect and real-time performance without introducing artifacts.

2. Adaptive Contrast resolution compensation

2.1 Human visual contrast resolution

The difference that human vision is the just noticeable difference is called JND, see equation (1) in reference [14] for the law on the change in contrast resolution with background gray level.

$$JND(i)=\begin{cases}22.98e^{-0.057i}, & 0\le i\le 47\\ 1.683-0.0083i+3.376\times10^{-5}i^2, & 47<i\le 255\end{cases} \quad (1)$$

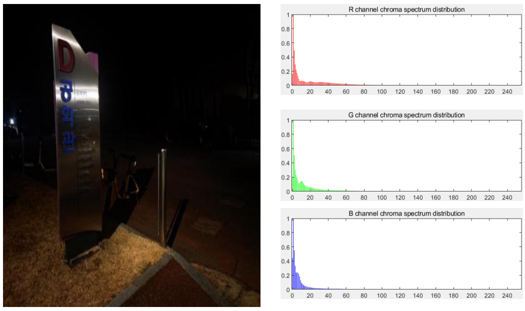
where i is the background gray level, $i \in [0,47]$ is dark vision, where the human eye's JND for image grayscale difference varies exponentially, and $i \in (47,255]$ is bright vision, where JND is in the range of 1.17 to 1.75 gray levels, which can be taken as (1.17+1.75)/2, i.e., 1.46.

2.2 CRC(Contrast resolution compensation)

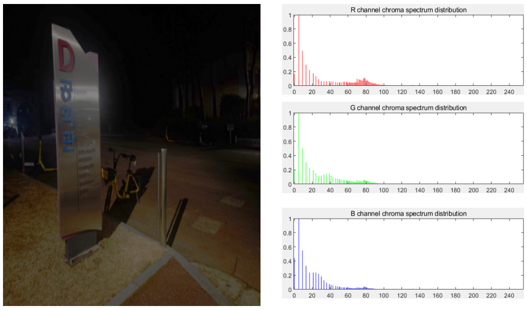
The image information is masked by the background in the low-light environment, in the vicinity of 0 gray level needs about 23 gray level difference to reach 1JND, machine vision can distinguish 1 gray level difference but the human eye can not distinguish. The just noticeable difference gray level difference for proportional integral operation, dark vision adjacent gray level compensation to 1JND, so that the original information can not be distinguished to precisely distinguishable. The principle of compensation for low-light images is as follows:

$$T(ch,x,y) = \begin{cases} O(ch,x,y) & ,O(ch,x,y) = 0 \\ k \sum_{i=0}^{O(ch,x,y)-1} JND(i), & O(ch,x,y) > 0 \end{cases} \tag{2}$$

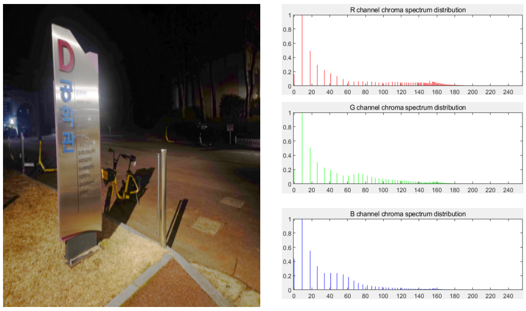
where ch denotes a certain channel of the human visual perception image, taking values in the range of [0,1,2,3]. When $ch = 0$, it indicates that the target image is a grayscale image, i.e., the grayscale Channel of the image; when $ch = 1,2,3$, it denotes the red channel, the green channel, and the blue channel respectively of the target image in the RGB space; $O(ch,x,y)$ and $T(ch,x,y)$ denote the original grayscale/chromaticity value before compensation and the target grayscale/ chromaticity value after compensation for a certain channel at the coordinates of the image pixel point (x,y) respectively, and the range of values is [0,255]. If the compensated target grayscale/chromaticity value is greater than 255, make it equal to 255, less than 1, make it equal to 0, otherwise there will be complementary color inverse color. The k value is the scale factor of CRC, as a variable parameter to adjust the compensation depth. The RGB three channels of the "Signboard "original image in Fig. 1 a) are subjected to CRC processing respectively, and the effect graphs of different scale factor k compensation and the grayscale/chromaticity spectra (grayscale/chromaticity level pixel distributions of the corresponding image channels) are shown in Fig. 1 b)~e).



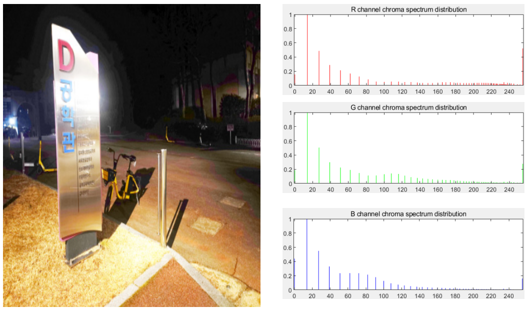
a) Signboard Original image



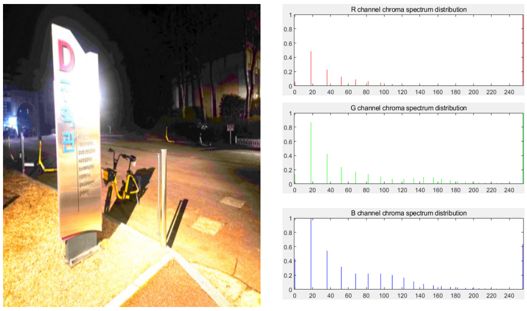
b) k=0.2



c) k=0.4



d) k=0.6



e) k=0.8

[Fig. 1] Compensation effects of different k

After the CRC, the information such as bicycle and ground masked in the original image of Fig. 1 a) Signboard can be clearly distinguished, which effectively improves the image quality. Visual perception image quality feature parameters such as average brightness factor, average contrast factor, average information entropy factor, average hierarchy factor and average bandwidth factor are used to analyze image features [15] for reference-free objective quality evaluation of images.

The darkness or lightness of an image is measured by AL (Average Luminance Factor):

$$AL_{ch}=\frac{1}{M\times N}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}L(ch,x,y),ch\in[0,1,2,3] \quad (3)$$

$$AL=\begin{cases}AL_{ch} & ,ch=0\\ \frac{1}{\sqrt{3}}\sqrt{\sum_{ch=1}^{3}AL_{ch}^{2}} & ,ch\in[1,2,3]\end{cases} \quad (4)$$

Where $L(ch,x,y)$ is the luminance of the pixel (x,y) of a certain channel in the image.

The contrast of an image, measured by AC (Average Contrast Factor):

$$AC_{ch}=\frac{\sum_{x=0}^{M-2}\sum_{y=0}^{N-2}C(ch,x,y)}{(M-1)\times(N-1)},ch\in[0,1,2,3] \quad (5)$$

$$AC=\begin{cases}AC_{ch} & ,ch=0\\ \frac{1}{\sqrt{3}}\sqrt{\sum_{ch=1}^{3}AC_{ch}^{2}} & ,ch\in[1,2,3]\end{cases} \quad (6)$$

where $C(ch,x,y)$ is the grayscale/chromaticity gradient of the pixel point (x,y).

The information contained in the image is measured by AIE(Average Information Entropy Factor):

$$IE_{ch}=-\sum_{i=0}^{255}p(ch,i)\log_{2}p(ch,i),ch\in[0,1,2,3] \quad (7)$$

$$AIE=\begin{cases}IE_{ch} & ,ch=0\\ \frac{1}{\sqrt{3}}\sqrt{\sum_{ch=1}^{3}IE_{ch}^{2}} & ,ch\in[1,2,3]\end{cases} \quad (8)$$

where $p(ch,i)$ denotes the probability of the distribution of the number of pixels of an image at the grayscale/chromaticity level of a given channel. In particular, $\log_{2}p(ch,i)=0$ when $p(ch,i)=0$.

$$HF_{ch}=\frac{NSL_{ch}}{256},ch\in[0,1,2,3] \quad (9)$$

$$AHF=\begin{cases}HF_{ch} & ,ch=0\\ \frac{1}{\sqrt{3}}\sqrt{\sum_{ch=1}^{3}HF_{ch}^{2}} & ,ch\in[1,2,3]\end{cases} \quad (10)$$

Where NSL_{ch}(Number of Spectral Line) is the number of the grayscale/chromaticity spectrum lines of a channel of the image.

Define ABWF (Average Bandwidth Factor) to reflect the structure of the image grayscale/chromaticity spectral distribution, denoted as:

$$BWF_{ch}=\frac{R(ch)-L(ch)+1}{256},ch\in[0,1,2,3] \quad (11)$$

$$ABWF=\begin{cases}BWF_{ch} & ,ch=0\\ \frac{1}{\sqrt{3}}\sqrt{\sum_{ch=1}^{3}BWF_{ch}^{2}} & ,ch\in[1,2,3]\end{cases} \quad (12)$$

where $R(ch)$ and $L(ch)$ denote the right boundary value (maximum luminance value) and the left boundary value (minimum luminance value) of the grayscale/chromaticity spectrum of a channel of the image, respectively.

In Fig. 1, the quality parameters of the image after compensated enhancement with different scale factor k values are shown in 〈Table 1〉, as the value of k increases, AB, AC, and ABWF of the image increase, and AIE and AHF of the image both increase first and then decrease.

〈Table 1〉 Image quality evaluation parameters of different k values

different k values	AL	AC	AIE	ABWF	AHF
original (Fig. 1a)	20.63	2.46	5.32	1.00	1.00
k=0.2 (Fig. 1b)	35.13	2.70	4.99	0.51	0.37
k=0.4 (Fig. 1c)	70.08	5.42	5.18	1.00	0.57
k=0.6 (Fig. 1d)	103.00	7.78	4.87	1.00	0.27
k=0.8 (Fig. 1e)	123.64	8.63	3.7	1.00	0.10

2.3 SCRCth(Segmented CRC with added threshold)

The image is compensated by proportional integration, which is prone to under- and over-compensation.As shown in Fig. 1 b), when the compensation ratio coefficient is taken as 0.2, the distribution of bright visual chromaticity level is concentrated, the chromaticity spectrum bandwidth is less than 1, and the contrast compensation is insufficient. As shown in Fig. 1 d) and e), when the compensation ratio coefficient takes too large a value (e.g., 0.6, 0.8), over-compensation occurs, and the image effect has the phenomenon of exposure.From equation (1), when the degree of compensation is less than 1.46 gray level differences, adjacent gray levels do not reach the minimum resolvable difference, compensation is no longer meaningful. Define DegreeC as the degree of compensation for contrast resolution:

$$Degree\ C=k\times JND(i),0\leq i\leq 255 \quad (13)$$

From equation (1), the JND of bright vision is between 1 and 2. In order to ensure that the grayscale/chromaticity level of bright vision reaches exactly distinguishable, let the degree of bright vision compensation DegreeC be 1.46, and then Th is the CRC threshold of the grayscale/chromaticity level corresponding to DegreeC=1.46. The algorithm for SCRCth is defined as follows:

$$T(ch,x,y)\begin{cases}O(ch,x,y) & ,O(ch,x,y)=0\\ k\sum_{i=0}^{O(ch,x,y)-1}JND(i) & ,Degree\,C\geq 1.46\\ O(ch,x,y)-T(ch,x,y)_{Th} & \\ \quad +k\sum_{i=0}^{O(ch,x,y)-1}JND(Th), & Degree\,C<1.46\end{cases} \quad (14)$$

where $T(ch,x,y)_{Th}$ is the compensated target grayscale/chromaticity at the threshold, proportional integral compensation is used when DegreeC>=1.46, and linear stretch compensation is performed when DegreeC<1.46.

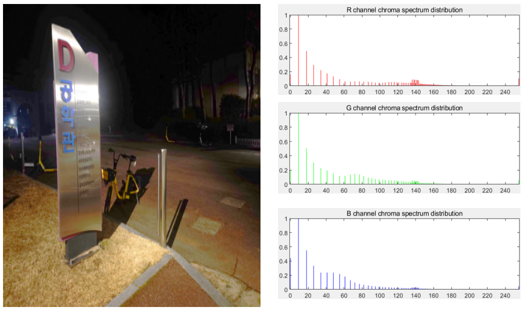
2.4 FBT(full-bandwidth transform)

As can be seen from Fig. 1, images with a wide grayscale/chromaticity spectrum bandwidth have better visual quality than images with a narrow spectral bandwidth. In order to make the image with full bandwidth grayscale/chromaticity spectrum (256 levels of bandwidth per channel), we propose a FBT (Full Bandwidth Transform) to optimize the processed image to a full bandwidth spectrum as shown in Eq. (10).

$$T_{FBT}(ch,x,y) = K_{BW}\frac{O_{FBT}(ch,x,y) - BW(ch,l)}{BW(ch,r) - BW(ch,l)} \quad (15)$$

Where, $O_{FBT}(ch,x,y)$ and $T_{FBT}(ch,x,y)$ denote the grayscale/chromaticity values of pixel point (x,y) before and after FBT of a particular channel respectively. $BW(ch,l)$ and $BW(ch,r)$ denote the left boundary value and right boundary value of the grayscale/ chromaticity spectrum of an image of a particular channel respectively, K_{BW} denotes the full bandwidth transform coefficient, Taking the values $K_{BW}=255$, $BW(ch,l)=0$, $BW(ch,r)=255$, the image after FBT has $ABWF=1$. FBT is image post-processing and works for all non-full bandwidth images.

For Fig. 1a) first SCRCth is performed and then FBT is performed, when k=0.4, the processed image is shown in Fig. 2.



k=0.4

[Fig. 2] Compensation effects of SCRCth

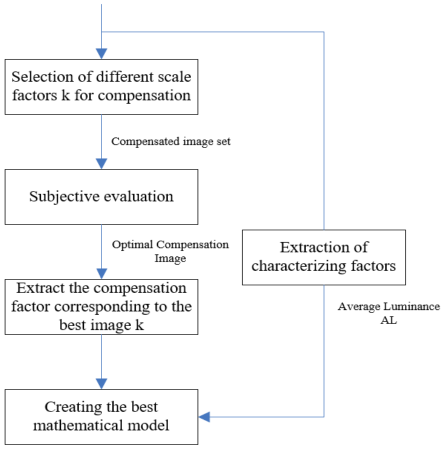
Under the same compensation scale factor, the AL, AC, and AHF of the images after adding threshold compensation are improved, and the AIE is unchanged, and no pseudo information is introduced, as shown in 〈Table 2〉. The text on the signage in the figure is clearer, and the bicycle is also revealed in the distance, which ensures the degree of compensation of bright vision while mining the information of the dark vision image.

〈Table 2〉 Image quality parameters with threshold compensation

Compensation image	AL	AC	AIE	ABWF	AHF
CRC[Fig.1 b)]	70.08	5.42	5.18	1.00	0.57
SCRCth[Fig.2]	70.60	5.68	5.18	1.00	0.59

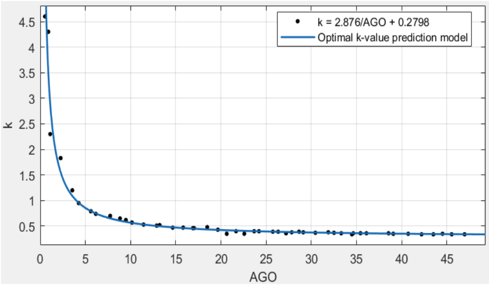
2.5 Adaptive extraction of k

In video image processing applications, the value of CRC scale factor k needs to be extracted adaptively per frame.Compensation coefficient of different compensation effect is different, as shown in Fig. 1, with the increase of the compensation ratio coefficient k value, the compensation effect of the image is first gradually changed from poor to good, and then gradually changed from good to poor, which is a convex function characteristics, with the best compensation ratio coefficient k. By extracting the video image characteristic factor, combined with subjective evaluation method to select the best image after compensation, establish the compensation ratio coefficient k automatic optimization model, so as to obtain the best compensation coefficient of single-frame image in real time, the modeling technology scheme is shown in Fig. 3.



[Fig. 3] Technical scheme for establishing automatic optimization model of k

Fifty original images with an average gray value between 0 and 47 in the low-light environment were collected, and nine different compensation scale coefficients k, ranging from 0.1 to 0.9, with a step size of 0.1, were taken for each image to obtain a sample set of test images. Referring to the observation conditions of the subjective evaluation method standard of digital TV image quality (GY/T134-1998), 30 observers are organized to select the best visual effect image by subjective evaluation. The observers will evaluate differently due to different cognitive directions, knowledge backgrounds, and emotions. The evaluation results were analyzed using mathematical statistics, and the final evaluation results were extracted by the mean value method by discarding the results of the overly biased evaluations for each set of data. The prediction model of the optimal compensation ratio coefficient k was fitted using the matalab fitting toolbox "Curve Fitting Tool" as shown in Fig. 4.



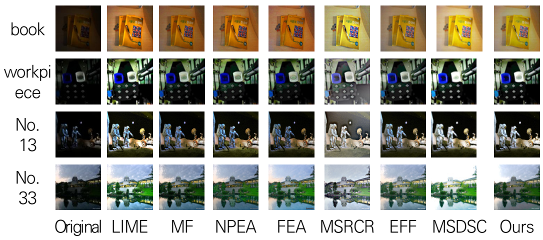
[Fig. 4] Prediction model of optimal K

The horizontal coordinate in the figure is AGO (Average Gary of Original image) of Original image, the vertical coordinate is the scale factor k. The original point in the figure is the experimental optimal point data, and the predictive model relationship of the optimal compensation scale factor k is as follows:

$$k = 2.876 / AGO + 0.2798, 0 < AGO \leq 47 \qquad (16)$$

3. Algorithm applicability validation

In order to test the applicability of this paper's algorithm in different scenarios, the video frame image book in low-light background, the video image of workpiece captured by the industrial robot vision platform workpiece and the two images No.13 and No.33 in the DICM(digital cameras, 69 captured images from commercial digital cameras, the images numbered 1-44 are low light images and we use these images) image dataset [16] are used to do the comparison of enhancement effect. Compare the LIME algorithm [9], MF algorithm [10], NPEA algorithm [11], FEA algorithm [7], MSRCR (Multi-scale Retinex withColor Restoration) algorithm [17] and EFF algorithm [6], and MSDSC(Multi-scale Depthwise Separable Convolution) algorithm [18] for low-light image processing, the parameter settings of the algorithms refer to the literature [6,17,18], the different algorithm processed images are shown in Fig. 5.



[Fig. 5] Enhancement effect of different algorithms

Analyzing from the subjective evaluation of human visual perception, all the above algorithms have enhancement effect on all the four original images. The video frame image “book” is taken to compare the objective image quality after processing by different enhancement algorithms and the evaluation parameters are AL, AC, AIE, ABWF, AHF and algorithm running time T (based on matlab R2018a test) as shown in 〈Table 3〉.

From the objective image quality evaluation parameters in 〈Table 3〉, it can be seen that among several algorithms, the MSRCR algorithm has the highest AL, AC, AIE, AHF of the processed image and has full bandwidth, but from the

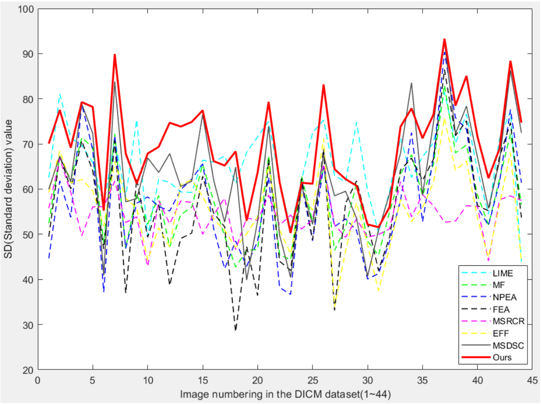
〈Table 3〉 Image quality evaluation parameters of different algorithms

Algorithms	AL	AC	AIE	ABWF	AHF	T/s
Book Original	24.89	0.99	5.13	0.44	0.39	—
LIME[9]	116.37	4.30	6.87	1.00	0.99	0.15
MF[10]	90.98	3.19	6.36	0.85	0.83	0.32
NPEA [11]	106.96	3.30	6.35	0.64	0.64	10.17
FEA[7]	107.56	4.42	6.48	0.79	0.77	0.30
MSRCR [17]	152.24	5.98	7.10	1.00	1.00	0.99
EFF[6]	111.28	3.51	5.73	0.99	0.87	0.29
MSDSC [18]	159.80	4.86	5.43	1.00	0.58	0.48
Ours	128.33	3.97	4.92	1.00	0.37	0.04

subjective evaluation of the enhancement effect of comparison in Fig. 5, it can be seen that there is a significant color bias and distortion after the MSRCR algorithm is processed. The LIME algorithm has a better enhancement effect of the original image "book", but from the "book" image and "workpiece" image processing effect to see the introduction of artifact noise, the overall color is reddish or greenish, over-enhancement of the original image. The MSDSC algorithm has a good enhancement effect on "book" images, but from the processing effect of the four images, there is a phenomenon of overall or local over brightness. Several other algorithms enhance the AHF higher than the original image because of the introduction of pseudo information, which is not present in this paper's algorithm.

The processing time of this paper's algorithm is only forty milliseconds per video image frame in matlab, which is much less than several other algorithms and more suitable for real-time video processing. The color of the image enhancement is natural and obvious, which can be applied to different scenes in low-light environment, and the enhancement does not introduce pseudo information, which is beneficial to the mining of dark visual information.

The performance evaluation test was performed on the low-light images (numbered 1-44) of the DICM dataset using the standard deviation (SD) metric.The standard deviation is the dispersion of image pixel gray values relative to the mean value, if the standard deviation is larger, it means the more dispersed the gray levels in the image and the better the image quality, respectively.The experimental results are shown in [Fig. 6], the red folded line is the result of this paper's algorithm, in 44 images, the optimal result of this paper's algorithm is 28, the second ranked is 8, there is no worst result, the overall performance is better than other algorithms, and there is a significant improvement.



[Fig. 6] Comparison of SD metrics of different algorithms in the DICM dataset

4. Conclusion

In this paper, based on the characteristics of human visual perception, based on the idea of contrast resolution difference compensation, we propose a segmented contrast resolution compensation with added threshold algorithm, and use the full-bandwidth transform for image optimization to effectively mine the dark visual information of the low-light environment, and establish an adaptive search and optimization extraction model for the compensation ratio coefficients. Experimental tests show that the adaptive compensation algorithm is applied to low-light video image enhancement with good real-time performance, effectively improves the image quality without introducing pseudo-information, and can be widely used in low-light scenes under different lighting conditions to mine dark visual image information.

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