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Noise Suppression and Enhancement of an Extremely Low – Light Video

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Abstract — **The two major characteristics of an extremely low-light video is the Dynamic Range (DR) and Signal to Noise Ratio (SNR). Here, enhancement and noise suppression of an extremely low-light video is proposed. Three steps are included in it. The first step is the denoising of extremely low-light video using Kalman filter approach. The next step is the enhancement of video using a Gamma correction technique. Most of the low-light video noises are suppressed by Kalman filtering. The remaining amplified noises are removed by Non Local Means (NLM) filter. The output video of this proposed work shows a better quality, denoised video with less processing time.**

Index Terms — **Extremely low- light videos, Kalman Filter, NLM filter, Tone Mapping.**

I. Introduction

In electronics engineering, video processing is a fundamental part of Signal processing. For video processing, we consider the High Dynamic Range (HDR) videos for the purpose of obtaining better results. Over the last several decades, there have been substantial improvements in modern digital cameras including its resolution and sensitivity. Despite these improvements, quality of videos in low-light conditions is still limited. Two considerable characteristics of an extremely low-light video are poor Dynamic Range (D.R) and very low Signal-to-Noise Ratio (SNR). There are various techniques employed to increase the dynamic range of an extremely low-light video. Most commonly used enhancement technique is Dehazing algorithm [2], [3], [17]. But, dehazing algorithm depends on the atmospheric light and its transmission medium. Estimation of transmission term in the hazy image acquisition model by using dehazing algorithm becomes unreliable in extremely lowlight conditions. Wavelet coefficients [11] based video enhancement can also be used for enhancement. But it has very high computational time. Another enhancement technique is tone mapping [4], [5] followed by a Gamma Correction. For obtaining a better video output quality, Histogram Equalization (HE) [6], [10] followed by gamma correction can be used.

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Several video denoising techniques are used in video processing. Most commonly used video denoising technique is Spatio-temporal filtering [7] and bilateral filtering [3], [13], [17]. Spatio-temporal filter aims only the videos slightly lower than the normal lighting conditions. Since this method was not originally aimed to low-light video enhancement task, some of the steps used, such as optical flow and segmentation, may not provide reliable results with low-light videos. Most of the denoising techniques require more computational time. Recently, a three stage processing scheme for denoising and enhancing dark videos was proposed. It is a modified version of the well known nonlocal means (NLM) filter [1],[5],[9],[10],[12],[18] for removing noise in an input video before and after tone-mapping by a logarithmic mapping function. A better denoised output for extremely low-light video is provided by Kalman filter approach [1], [10], and [16]. Kalman filtering is based on the prediction and correction of video frames and most of the video noises can be removed by this method. An extremely low-light video can be enhanced efficiently by the use of Gamma correction. Kalman filter and NLM filter can be used to get a better denoised video output.

II. Methodology

From the surveys, it is clear that most of the video denoising techniques require more computational time. A better denoised output will be given by Kalman filter and NLM filter. Similarly, tone-mapping provides a better enhanced output. In this work, tone-mapping includes gamma correction and histogram equalization. Most of the video noises are removed by Kalman filter. The remaining amplified noises are removed by NLM filter.

A. Block Diagram

The proposed work includes three steps. The diagrammatic representation of the proposed work is given in Fig. 1.

B. Extremely Low Light Videos

Two major characteristics of low-light videos are high level of noise (i.e., low SNR) and low dynamic range. Since these characteristics influence mutually on both denoising and tone mapping performances, they should be analyzed deliberately before developing low-light video enhancement technique. There are various kinds of noises present in a low light image. They are shown in Fig. 2.

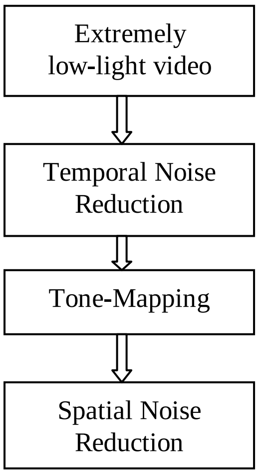

Fig. 1.Block diagram of the proposed method

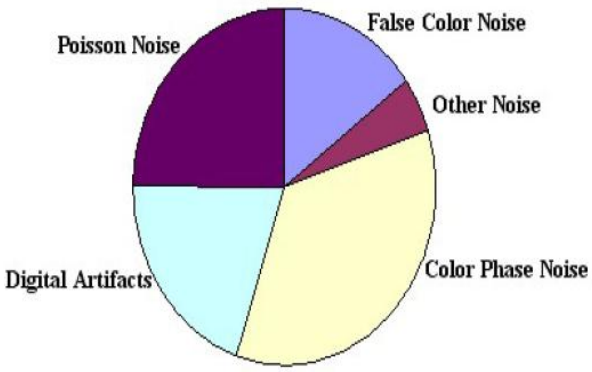

Fig. 2.Elements of camera noise [21]

From the Fig 2, it is clear that color phase noise is the important noise present in the image. It is a random fluctuation in the image caused by time domain instabilities (jitter).In video and television, noise refers to the random dot pixel pattern that is superimposed on the picture. As a result of electronic noise, the 'snow' that is seen with poor (analog) television reception. Interferences and static are other forms of noise, in the sense that they are unwanted, though not random, which can affect radio and television signals. The characteristics of extremely low-light video can be studied from its histogram. For an example, extremely low light video frame and its corresponding histogram is shown in Fig 3. Most of the pixels in an extremely low light video are assigned to a very narrow region with low intensities. Also, the shapes of histograms of each color channels are almost identical. As the illumination level is decreased, the peak of histogram moves towards the zero, thus it becomes an "L-shape".

a. Illuminance

In photometry, the total luminous flux incident on a surface per unit area is referred to as the illuminance. Illuminance calculation includes all light reaching the point of measurement from an 180^{o} hemisphere. The unit of illuminance is lux. A camera with better low light capability will have a lower lux rating. In this work, consider the illuminance value as 0.03 lux (Extremely low-light video).

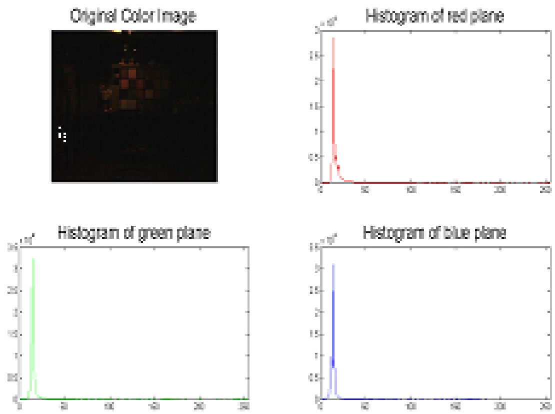

Fig. 3. Histogram of an extremely low-light video frame.

b. Dynamic Range

Dynamic range of the video can be defined as the difference between the lightest light and darkest dark which can be seen in a photograph. Once our subject exceeds the camera's dynamic range, then the darks become black blobs and highpoints downpour to white. The extremely low-light videos have a very limited dynamic range.

C. Temporal Noise Reduction

In this work, an effective motion adaptive temporal filtering based on the Kalman filter approach is used as a temporal noise reduction. Rudolf Emil Kalman had the idea of Kalman filter for the first time in the year 1958. The Kalman filter is a recursive predictive filter and it is based on the use of state space methods and recursive algorithms. It estimates the state of a dynamic system. This dynamic system can be distributed by some noise, mostly assumed as white noise. To improve the estimated state the Measurements are used by the Kalman filters that are similar to the state but disturbed as well. Kalman filter consists of two steps, Prediction and Correction. In the prediction step, the state is predicted with dynamic model. In the second step, it is corrected with the observation model. The ongoing discrete Kalman filter cycle. The measurement and update process of Kalman filter is shown in the Fig. 4.

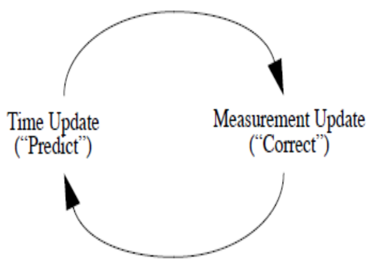

Fig. 4. . Meaurement and update of kalman filter time.

The filter performance is listed below:

1. Initialization.
   - Filter gain = G
   - Noise variance estimate: = V
   - Use the first image as the prediction seed
     $I^{-}_{k} = I_k$
   - Use the variance estimate as the error seed
     $E^{-}_{k} = V$
2. Correction.
   - Compute the Kamlan Gain
     $K_k = E^{-}_{k} / (E^{-}_{k} + V)$
   - Update the image prediction with the (M_k) measurement
     $I_k = G*I^{-}_{k} + (1.0\text{-}G)*M_k + K_k (M_k - I^{-}_{k})$
   - Update the variance estimate:
     $E_k = E^{-}_{k} (1-K_k)$
3. Prediction.
   - Predict the next image
     $I^{-}_{k+1} = I_k$
   - Predict the variance:
     $E^{-}_{k+1} = E_k$
4. Update values.
   $E^{-}_{k} = E^{-}_{k+1}$
   $I^{-}_{k} = I^{-}_{k+1}$
5. Repeat 2, 3, and 4.

D. Tone Mapping

After the temporal noise is reduced, dynamic range of the low-light video is required to be stretched for enhancing visibility. For obtaining high dynamic range images, various techniques are used. In this work, Histogram adjustment with gamma correction is used.

a. Histogram Adjustment

Histogram equalization is a technique of contrast adjustment by using the image's histogram. This method usually increases the global contrast of several images, peculiarly when the usable data of the image is represented by close contrast values. Through this histogram adjustment, the intensities of the images can be distributed preferably on the histogram. This allows for areas of lower local contrast to achieve a higher contrast. Histogram equalization accomplishes this by effectively spreading out the most frequent intensity values.

a. Gamma Correction

Gamma is an important but seldom understood characteristic of virtually all digital imaging systems. It defines the relationship between the numerical value of a pixel and its actual luminance. Gamma correction is explained by the power- law expression.

$$V_{out} = AV_{in}^{\gamma} \qquad (1)$$

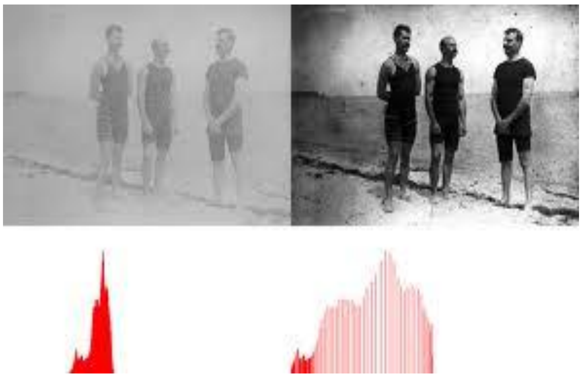

Fig. 5. Concept of Histogram Equalization.

Where A is a constant and in the common case, A = 1, inputs and outputs are typically in the range 0-1. A gamma value < 1 is called gamma compression. Conversely a gamma value > 1 is called gamma expansion.

E. Spatial Noise Reduction

A large amount of noise can be removed by temporal noise reduction technique. The remaining noise can be exaggerated by the tone-mapping step. Unlike any other video enhancement techniques that utilize a spatiotemporal filter, the proposed method only applies a temporal filter for noise removal before the tone mapping step. Therefore, an additional filtering in spatial domain is desired to reduce remaining noise. The spatial domain filtering is done by NLM filter. It builds on the separable property of neighborhood filtering to offer a fast parallel and vectorized implementation. In practice, the NLM approach is much faster than a serial, non vectorized implementation and it scales linearly with image size. Practical attempts of coding NLMeans filter have led to slow implementations. Depart from the sliding window scheme typically adopted by neighborhood filtering implementations and resort on more sophisticated ideas leading to a faster implementation. The NL-means schemes grow fast when an image contains many repetitive structured patterns. It uses redundant information to limit the noise by performing a weighted average of pixel values. Assume, images are defined over a discrete regular grid of dimension'd'. Denote the original noisy image by 'v'. The value of the restored image 'u' at a sight s".

$$u(s) = \frac{1}{z(s)} \sum_{t \in N(s)} w(s,t) v(t) \qquad (2)$$

$$w(s,t) = g_h (S_{dx} (s+P) - S_{dx} (s-P)) \qquad (3)$$

Where, g_h is a continuous non –increasing function , S_{dx} corresponds to the discrete integration of the squared difference of the image 'v' and its translation by 'dx' , 'P' is the patch and 's' is the site of an image.

III. Performance Evaluation

To evaluate quantitative performance of denoising and enhancement method, some full-reference image quality metrics are used. A reference video frame under 80 lux is used for computing evaluation index. The Peak Signal-to-Noise Ratio (PSNR), Global Contrast Factor (GCF), Mutual Information (MI) and the processing time are evaluated in this work.

A. Peak Signal – to- Noise Ratio

PSNR is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. PSNR is most easily defined via the Mean Squared Error (MSE). Given a noise-free m × n monochrome image ‘I’ and its noisy approximation ‘K’, MSE is given by,

$$\mathrm{MSE}=\frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j)-K(i,j)]^2 \qquad (4)$$

$$\mathrm{PSNR}=10\log_{10}\frac{\mathrm{MAX}_I^{\,2}}{\mathrm{MSE}} \qquad (5)$$

B. Global Contrast Factor

Contrast in image processing is usually defined as a ratio between the darkest and the brightest spots of an image. GCF [20] uses contrasts at various resolution levels in order to compute overall contrast. GCF measures richness of detail as perceived by a human observer.

$$\mathrm{GCF}=\sum_{i=1}^{N} W_i \times c_i \qquad (6)$$

Where ‘i’ is the corresponding enhanced pixel, ‘N’ is the number of iterations is the weight factor and ‘c’ is the average local contrast. The average local contrast can be written as (7).

$$c_i=\frac{1}{w\times h}\sum_{i=1}^{w\times h} lc_i \qquad (7)$$

Where, ‘w’ is the pixel width, ‘h’ is the pixel height and ‘lc_i’ is the local contrast.

$$lc_i=\frac{|L_i-L_{i-1}|+|L_i-L_{i+1}|+|L_i-L_{i-w}|+|L_i-L_{i+w}|}{4} \qquad (8)$$

C. Mutual Information

The mutual Information (MI) [19] between two variables is a concept with roots in information theory and essentially measures the amount of information that one variable contains about other.

$$\mathrm{MI} = H(A) + H(B) - H(A, B) \qquad (9)$$

Where, H () is the entropy of images A and B, H (A, B) is the Joint entropy.

IV. Experimental Results

For the performance evaluation of the work, extremely low-light video captured in the dark room and outdoor are considered. The illumination level of the input is 0.03 lux (Below 0.1 lux).

(a) (b)

Fig. 6. (a) Frame of indoor video (b) Frame of outdoor video

A. Temporal Noise Reduction

Temporal noise reduction is done by Kalman filter. It is based on prediction and correction of video frames. Before denoising the video, the input frames are converted to gray scale. Initially, there is no previous frame to predict. So, the first frame itself is considered as the predicted and noisy frame.

B. Tone Mapping

Tone-mapping includes Gamma correction and histogram equalization. The input videos are under extremely low-light condition. Its Dynamic Range is limited and has less PSNR. The enhanced video frames and their corresponding histograms are shown in Fig. 7 and Fig. 8.

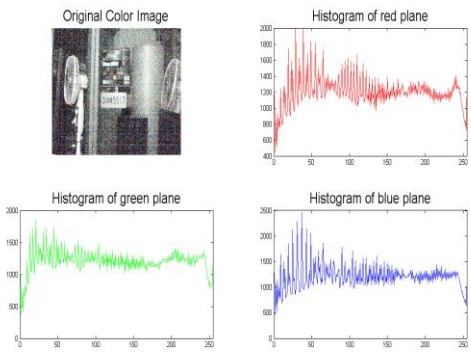

Fig. 7. Enhanced frame of indoor video

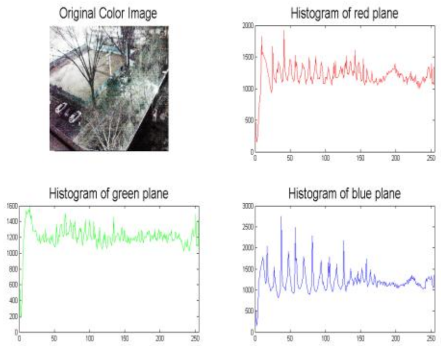

Fig. 8. Enhanced frame of Outdoor video.

C. Spatial Noise reduction

The spatial noise reduction is done by using NLM filter. Since, Non Local Means filtering requires more computational time. But in this work, NLM filtering consumes very less computational time

Fig. 9. Output indoor video frame

Fig. 10. Output outdoor video frame.

Table 1. Quantitative Performance Evaluation of Indoor Video

Matric	Indoor Video
PSNR	25.72143
MI	0.1169
GCF	2.2450
Processing Time(s/frames)	7.97

Table2. Quantitative Performance Evaluation of Outdoor Video

Matric	Indoor Video
PSNR	25.7600
MI	0.2235
GCF	1.4428
Processing Time(s/frames)	7.37

V. CONCLUSION

In this work, the characteristics of low-light videos captured in an extremely low light condition are analyzed. The proposed method consists of a denoising technique and an enhancement technique. The extremely low-light videos have very limited PSNR and dynamic range. By applying Kalman filter approach, it removes most of the noises from the video. The enhancement technique is done by tone mapping approach. Tone Mapping includes a gamma correction and histogram equalization. Most of the noises are removed from the video by Kalman filter. The remaining amplified noises are removed by NLM filter approach. The experimental results shows that, the output video of the proposed work have high PSNR and a noticeable enhancement. Also, the computational time is very less. Extremely low-light video denoising and enhancement is based on uncompressed videos. It uses two filters namely Kalman filter and NLM filter for denoising. A PSNR of 25 can be obtained by this method.

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