REAL-TIME CONTENT ADAPTIVE CONTRAST ENHANCEMENT FOR SEE-THROUGH FOG AND RAIN

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ABSTRACT

In this paper we present a novel algorithm for improving the visibility of surveillance videos degraded by fog and/or rain. The proposed algorithm adaptively enhances the global and local contrast of a surveillance video. The algorithm is inspired on the human visual system, and accounts for the perceptual sensitivity to noise, compression artifacts, and the texture of image content. The model is combined with the classic Contrast Limited Adaptive Histogram Equalization (CLAHE) method to adaptively enhance surveillance videos. We have implemented a real-time video enhancement system and performed extensive experimental testing over a video database containing common surveillance videos recorded under fog and rain conditions. The proposed approach significantly improves the visual quality of surveillance videos by removing fog/rain effects, as well as reducing noise and artifacts.

Index Terms— Video Quality Enhancement, Visual Surveillance, Contrast Enhancement, Human Visual System

1. INTRODUCTION

Video quality enhancement plays an important role in surveillance video applications. Poor video quality reduces the effectiveness of human operators responsible for monitoring the surveillance video displays, and it decreases the performance of video analytic algorithms. Improved perceived visual quality combined with improved video analytics results in general in more accurate detection of threats and fewer false alarms.

In outdoor surveillance applications, bad weather conditions such as heavy fog or rain hide the details of the scene, and significantly reduce the visibility by degrading the contrast information of the video signal. In this type of situations see-through rain and fog capabilities are highly desired to enhance the contrast and improve the visibility. However, noise and compression artifacts present in surveillance video pose challenges to such enhancement algorithms. These algorithms must improve the quality of the video and at the same time not increase the noise and compression artifacts present in the input video signal.

This paper proposes a novel contrast enhancement algorithm to meet Human Visual System need which can improve the visibility of videos under fog or rain weather conditions, while minimizing the enhancement of noise and compression artifacts.

2. LITERATURE REVIEW

There are two types of contrast enhancement methods to deal with rain and/or fog: physics-based and histogram-based. Most physics-based haze removal methods such as [1] and [2] are limited by the conditions under which the model is valid. More advanced models are required to describe complicated phenomena, such as the sun's influence on the sky region, and the blueish hue near the horizon. Also these method are not suitable for general outdoor surveillance videos that present heavy fog or rain conditions, and low quality of images with noise and compression artifacts. Under these conditions, it is very hard to get a valid imaging model. Finally this kind of methods are mainly for still images and they do not consider inter-frame information, which will introduce global flickering effects while applying to video sequences.

Histogram processing (Global and Local Histogram Equallization) is the second approach to enhance image contrast. Local histogram equalization methods, such as the ones in [3] and [4], provide better performance than global method to reveal more image local details and give stronger image enhancement performance. Some methods like [5] [6] perform simple local histogram equalization by mapping the local histograms of different portions of image to the equalized local histograms, while some others do the adaptive local histogram equalization [3] [4] [7]. One of the most classic adaptive local histogram equalization methods is the Contrast Limited Adaptive Histogram Equalization (CLAHE) method, which was first proposed by Zuiderveld [8]. CLAHE is the widely studied and frequently used [9][10]. The CLAHE method addresses the limitation of the global histogram equalization method by exploiting local image statistics, and can be easily and efficiently implemented. Therefore, we leverage

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the CLAHE algorithm to create a novel approach to improve visibility of surveillance videos under rain and fog conditions.

3. CONTENT ADAPTIVE LOCAL CONTRAST ENHANCEMENT ALGORITHM

3.1. Proposed Algorithm

The algorithm proposed in this paper is intended to overcome the limitation of the original CLAHE algorithm. To achieve this, the method considers local image statistics. The proposed concept is based on the idea that the human vision system is more sensitive to the noise and artifacts in homogeneous regions of an image, than noise and artifact in regions with more texture [11]. Therefore less enhancement is desired in the homogeneous regions to prevent over-saturation, noise over-enhancement, and belts.

The basic idea is to enhance more in structured (or textured) regions to bring out more image details, but enhance less in homogeneous (or flat) regions to avoid enhancing the noise and the compression artifacts. The local content of the image is calculated as the tile-wise intensity variance. The variance map is then scaled to generate a parameter $\nu_{i,j}$ (i,j denotes the tile index). The content adaptive local contrast enhancement concept is illustrated in Fig 1.

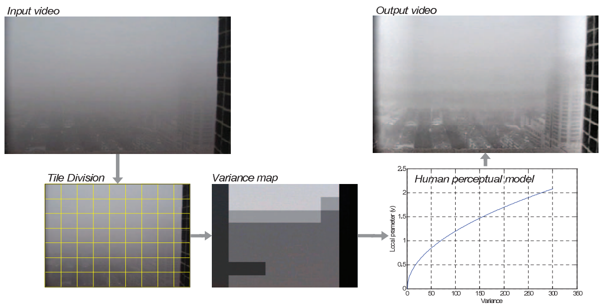
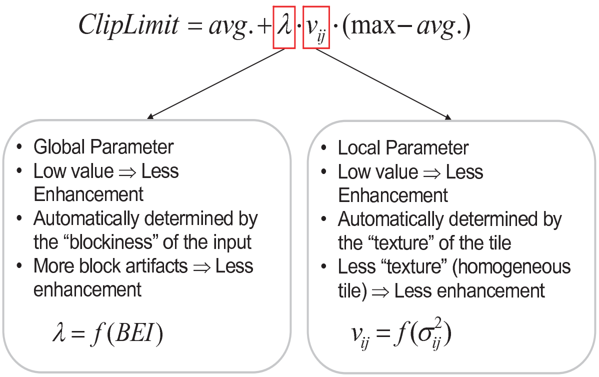


Fig. 1. Local Content Adaptive Enhancement Example

Based on the content adaptive parameter, $\nu_{i,j}$, we propose a new $ClipLimit$ calculation defined as Eq 1.

$$ClipLimit = avg. + \lambda\nu_{i,j}(max. - avg.) \tag{1}$$

As shown in Fig 2, besides the local adaptive parameter $\nu_{i,j}$ our approach also uses a global parameter λ. The global parameter is estimated adaptively based on the amount of block artifacts in the entire image. We use BEI (Block-Edge Impairment) [12] as the metric to quantify the amount of block artifacts in the image. The metric is defined as the ratio of the between-block difference and the within-block difference. The larger the value, the more severe the block artifacts. Accordingly, λ is smaller, and less enhancement is applied. In conclusion, these two enhancement parameters are experimentally designed based on human visual system.



$$ClipLimit = avg. + \boxed{\lambda} \cdot \boxed{v_{ij}} \cdot (\max - avg.)$$

- Global Parameter
- Low value ⇒ Less Enhancement
- Automatically determined by the “blockiness” of the input
- More block artifacts ⇒ Less enhancement

$\lambda = f(BEI)$

- Local Parameter
- Low value ⇒ Less Enhancement
- Automatically determined by the “texture” of the tile
- Less “texture” (homogeneous tile) ⇒ Less enhancement

$v_{ij} = f(\sigma_{ij}^2)$

Fig. 2. Example to show the Cliplimit calculation.

The adaptive nature of the proposed algorithm enhances the video contrast such that the output image is pleasing to the human observer. The method proposed in this paper has the following advantages over other local adaptive histogram equalization methods [8][7]:

- Adaptive parameters based on local image statistics and global image properties enable a contrast enhancement algorithm that does not require user configuration. The parameters are automatically determined by the algorithm based on the input video signal. On the other hand, most state-of-the-art video contrast enhancement algorithm requires manually specified input parameters to determine the level of enhancement applied by the algorithm.

- The level of enhancement for each region of the image is determined by local image statistics. These statistics are estimated on a tile by tile basis, allowing the system to use a different parameter value for each tile. Because human perception is more sensitive to noise and artifacts in homogeneous regions, the algorithm enhances less in homogeneous regions and enhances more in regions with more texture. This reduces the enhancement of noise in those regions of the image where humans are more sensitive to noise and compression artifacts. The variance of each tile is used to estimate the ”texture” and less enhancement is applied to those tiles with low variance.

- A global parameter controls the amount of overall enhancement that is applied to a specific video. The global parameter is computed automatically based on the “blockiness” of the input video signal where the blockiness is measured using BEI. Video with stronger compression artifacts are enhanced less, minimizing the enhancement of the artifacts.

3.2. Algorithm Implementation

The flow chart of the proposed contrast enhancement algorithm is illustrated in Fig 3.

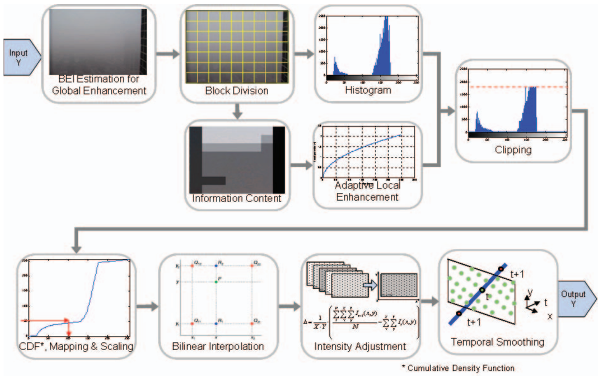


Fig. 3. Flow Chart of the final content adaptive contrast enhancement algorithm.

1. The first step is to retrieve images from the input video source and get the color channels information for processing. Here we can only process Y channel to reduce the overall algorithm computational speed (as the first block in Fig 3), or at the same time we can also process Cr and Cb color channels to enhance color information to reveal more color information.
2. Then the image's "blockiness" level is estimated by the BEI metric. The whole image's BEI metric value is used to calculate the global image enhancement parameter λ.
3. Similar to the original CLAHE algorithm [8], we divide the image into different tiles for local enhancement. For each image tile, we estimate its histogram information and at the same time estimate its "texture" information by calculating its variance. The local "variance" information is used to calculate the local image enhancement parameter $\nu_{i,j}$.
4. For the histogram of each tile, we clip the histogram based on the global and local histogram parameters (λ and $\nu_{i,j}$) and Eq 2.
5. Histogram mapping and bilinear interpolation: These two steps are similar to the original CLAHE algorithm [8].

In addition, we perform post-processing to further improve the video quality.

- The first post-processing step is to adjust the illumination of the current frame using the intensity mean of previously processed images. The purpose of this step is to achieve a current image with similar overall intensity level to the intensity level of previous images. This reduces the global flickering effect of the video sequence. The equation for the past mean adjustment process is as Eq 2:

$$\Delta = \frac{1}{X \cdot Y} \cdot \left[\frac{\sum_i^N \sum_x^X \sum_y^Y I_{t-i}(x,y)}{N} - \sum_x^X \sum_y^Y I_t(x,y) \right] \tag{2}$$

  here N is the number of past frames, t denotes the frame number and I is the intensity level image (Y channel) of the input video signal.

- Contrast enhancement also enhances the noise in the image. Therefore the second post-processing step in this algorithm is to reduce this noise. Here we are using the $1D$ temporal smoothing based on the bilateral filter. Comparing to other low pass noise removal filters, such as Gaussian filter, bilateral filter has the advantage of removing noise while preserving edge structures [13].

4. EXPERIMENTAL RESULTS

Extensive experiments were conducted to validate the effectiveness of the proposed algorithm. In Fig 4, we can see that the contrast enhancement result from our algorithm produces less enhancement of noise and artifacts. Additionally, our approach produces less color distortion and no belts effects.

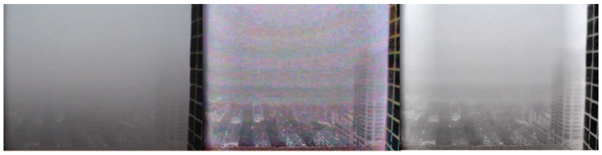


Fig. 4. Comparison with the classic CLAHE method. The left figure is the original image from the testing video. The middle figure shows the result from the CLAHE method. The right figure shows our result.

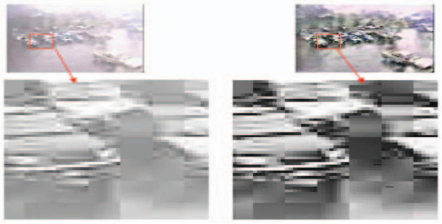


Fig. 5. The result without adaptive global enhancement (Left: input video; Right: output video.) The block artifacts due to compression are over enhanced.

We tested the effects of global parameter λ. In Fig 5, the input image on the left already has a lot of compression block artifacts, as a result the BEI value for this image is very high. Since the adaptive scheme was not used for the classic CLAHE method, the block artifacts are over enhanced, as shown in the right figure of Fig 5. In Fig 6, the input image on the left is highly compressed, resulting in an input image with strong block artifacts. In this case, the global parameter λ is set to a small value. The adaptive nature of our approach results in the application of weaker enhancement. From the right image of Fig 6 we can see that the resulting image has better quality and at the same time the block artifacts are not over enhanced.

Fig. 6. The result with adaptive global enhancement based on the block artifacts estimation. (Left: input video; Right: output video.

(a) (b)

Fig. 7. Here we show some contrast enhancement comparison results. In Fig 7(a) we show the input image. In Fig 7(b) the contrast enhancement result using the normal global contrast enhancement method (the left figure) and our proposed algorithm (the right figure) are compared.

In Fig 7 we use global contrast enhancement algorithm and our proposed algorithm to enhance the video. The right image of Fig 7(b) illustrates a case where both the image intensity and color are enhanced, and as a result the output image has more color information. By comparing with the result (the left image of Fig 7(b)) from the traditional global contrast enhancement algorithm, we can also observe that using the proposed approach the output image is clearer and more vivid, and the enhancement is equally spread over different image regions. In contrast, the image obtained from global contrast enhancement (the left image of Fig 7(b)) shows much less details. There are also some color distortions because of global color histogram equalization (such as some blur color on the edges of the buildings and the color of the middle red bus is changed to yellow). The comparison shows that our algorithm performs better than traditional global contrast enhancement methods.

Superior to state-of-the-art methods, the proposed algorithm is also computationally very efficient, achieving real-time performance at 30fps for $D1(720\times480)$ resolution video with less than 5% of the CPU cycles, which well meets pratical visual surveillance requirements. The system for our testing is a workstation with Intel Xeon 3.00GHZ CPU and 2GB memories.

5. REFERENCES

[1] S.G. Narasimhan and S.K. Nayar, "Contrast Restoration of Weather Degraded Images," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 25, no. 6, pp. 713–724, Jun 2003.

[2] Robby T. Tan, "Visibility in bad weather from a single image," in *Proceedings of IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR 2008)*, June 2008.

[3] Yafei Tian, Qingtao Wan, and Fengjun Wu, "Local histogram equalization based on the minimum brightness error," in *Proceedings of The Fourth International Conference on Image and Graphics*, August 2007, pp. 58–61.

[4] R. Dale-Jones and T. Tjahjadi, "A study and modification of the local histogram equalization algorithm," *Pattern Recognition*, vol. 26, no. 9, pp. 1373–1381, 2007.

[5] Asaf Golan and Avraham Levy, "Method of adaptive image contrast enhancement," US Patent 20070031055.

[6] Jie Zhao and Shawmin Lei, "Methods and systems for automatic digital image enhancement with local adjustment," US Patent 20070092137.

[7] Richard S. Szeliski, "Locally adapted histogram equalization," US Patent 6650774.

[8] Karel Zuiderveld, "Contrast limited adaptive histogram equalization," *Academic Press Graphics Gems Series: Graphics gems IV*, pp. 474 – 485, 1994.

[9] Ali M. Reza, "Realization of the contrast limited adaptive histogram equalization (clahe) for real-time image enhancement," *The Journal of VLSI Signal Processing*, vol. 38, no. 1, pp. 35–44, 2004.

[10] H. Malm, M. Oskarsson, E. Warrant, P. Clarberg, J. Hasselgren, and C. Lejdfors, "Adaptive enhancement and noise reduction in very low light-level video," in *Proceedings of IEEE 11th International Conference on Computer vision*, October 2007, pp. 1–8.

[11] Gaetano Scognamiglio, Andrea Rizzi, Luigi Albani, and Giovanni Ramponi, "Sharpness enhancement," US Patent 6847738.

[12] H.R. Wu and M. Yuen, "A generalized block-edge impairment metric for video coding," *IEEE Signal Processing Letters*, vol. 4, no. 11, pp. 317–320, 1997.

[13] C. Tomasi and R. Manduchi, "Bilateral filtering for gray and color images," in *Proceedings of the Sixth International Conference on Computer Vision (ICCV)*, January 1998, pp. 839–846.