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Video Dehazing Based on DCP and Type-2 Fuzzy Sets with a Guided Filter

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Abstract*:* Video dehasing refers to techniques for improving the visibility and quality of videos recorded under unfavourable weather conditions like haze or fog. This research presents a novel approach to improve the quality and exposure of these kinds of films. Using a regulated filter, type 2 fuzzy sets, and the dark-channel-prior, the method creates videos with higher resolution. The dark-channel prior estimates atmospheric light conditions and also transmission maps for each frame in the video. By integrating type-2 fuzzy sets, the approach effectively handles uncertainties and blurring in out-of-focus scene information, improving the robustness and accuracy of the dehazing process. Additionally, a guided filter refines the transmission maps and enhances the video images, reducing artefacts and improving visual quality. To gauge the effectiveness of the approach, quality evaluation metrics like Peak-Signal to Noise-Ratio (PSNR), Structural-Similarity Index (SSIM), Lightness-Order-Error (LOE), and Naturalness-Image-Quality-Evaluator (NIQE) are utilized. This research contributes to the further development of image equalization techniques and their practical applications across various fields.

Keywords*: Dark Channel Prior, Type-2 Fuzzy Sets, Guided Filter, PSNR, SSIM, NIQE, LOE*

1. INTRODUCTION

Videos shot in hazy or foggy conditions often suffer from reduced visibility, distorted colors, and loss of important details. This research presents a novel approach to improve the quality and exposure of these kinds of films. Using a controlled filter, type 2 fuzzy sets, and the dark channel-prior, the method creates videos with greater resolution. Recent years have seen substantial progress in video dehazing through the development of advanced algorithms and techniques.

One notable approach that has garnered attention is the integration of dark-channel-prior, type-2 fuzzy sets, and guided filters. This research paper delves into the potential of combining these methods to effectively tackle the challenges of video dehazing.

To determine the degree of smog in a specific region, the dark channel prior uses the lowest possible intensity value in a limited window called the dark channel. By estimating atmospheric light and transmission maps using this method, haze can be effectively removed and scene visibility improved. To address the inherent uncertainty and vagueness of hazy scene information, Type-2 fuzzy sets are integrated into the dehazing process, resulting in a more robust and accurate algorithm. To refine the transmission map and enhance the video, frames, guided filter is used for reducing the artifacts and further improving of visual quality.

In order to show that these methods may be effectively integrated for video dehazing, even in difficult situations, a thorough analysis of their application is presented in this work. The proposed method has the potential to significantly impact a variety of applications where video quality and clarity are critical, offering practical solutions to real-world challenges.

2. LITERATURE REVIEW

Jehoiada Jackson et al. [1] presented a rapid de-hazing approach that uses the Rayleigh scattering method and the dark channel prior for single images. This work provides a quick and efficient way to estimate atmospheric light. The average, minimum, and maximum values of each pixel in each of the three RGB color channels are what the algorithm depends on. It also builds an emission coefficient model that utilizes the concepts of Rayleigh scattering. This model helps estimate the initial gearbox map, which is subsequently improved by using a fast filter to remove erroneous halo edges. The algorithm uses the atmospheric scattering model to reconstruct the haze-free image.

Cong Wang et al. [2] suggested a single picture enhancing strategy that use the dark channel to avoid excessive time complexity and edge effects. They devised a four-step weighting method to assess ambient light properly and used the dark channel to calculate coarse transmittance. In

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addition, they used the grayscale picture of the original image to improve the transmittance. A model of air scattering was then utilised to remove fog and restore a clean image. To address the constraints of the dark channel in dealing with bright areas, they used edge detection and maximum interclass variance to distinguish between sky and non-sky regions. Then, non-sky portions received improved defogging treatment, while sky parts were enhanced using a sequential segmentation process.

Jeong et al. [3] proposed a novel end-to-end deep learning approach for real-time single picture correction. The suggested neural network model uses a zoomed convolutional group to reduce computational complexity while retaining good performance. This is performed via a coarse-to-fine method that modifies the sampling ratio and number of convolutional blocks throughout the initial and later phases of operation. Experimental results on a publicly accessible dataset show that the suggested strategy delivers real-time performance similar to a cutting-edge technology, with a processing speed that is 10.4 times quicker. Despite having a peak signal-to-noise ratio that is 0.8 dB lower than

Abeer Ayoub et.al[6] proposed a video quality enhancement method using a dehazing algorithm, which was advanced by means of a pre-processing step to remove the noise and limited dynamic range of the frames. Two video sequences, NIR and visible spectrum sequences, were considered for the study to examine the effect of haze mathematically. The effect of the attenuation parameter α and the attenuation weight ω in the dehazed images was considered, and from this, it has been proven that the proposed algorithm is effective in enhancing the quality of NIR and visible spectrum videos.

Xinyi Zhang et al [7] introduced the Real-world Video DEhazing dataset, which includes real-world video pairings with and without haze. They also suggested the Confidence Guided and Improved Deformable Network to address the use of temporal redundancy in blurred pictures. The the SOTA approach, the suggested network's overall performance is outstanding.

Recent work by Salazar-Colores et al [4] introduces an improved single image dehazing method. Artifacts in the output image are reduced due to a modified dark channel computation used in their approach, and the method outperforms some of the state-of-the-art techniques in terms of recovery speed and quality. The empirical results show that this technique works well in high-resolution images and real-time videos.

The video dehazing method proposed by R. Raj Bharath et al [5] using the Dark Channel priority approach estimates the propagation map using a pre-dark channel to enhance the accuracy of the transmission predictions. Refining this technique further, the authors have taken into consideration the spatio-temporal coherence of the DCP across consecutive frames. Furthermore, the authors have identified the illumination irregularities of images and have modified their approach to increase the effectiveness of the method in such cases. The innovative method should be immensely useful in a wide range of video deblurring applications, from surveillance to traffic,monitoring, and outdoor photography. experimental findings reveal that the blurred scenes in the REVIDE dataset are more realistic than the synthetic datasets, and its performance is superior to other dehazing techniques available.

3. METHODOLOGY

Our approach is based on the main mechanisms brought forward by the Dark-Channel prior method. Figure 1 represents a schematic overview of our approach. This technique takes hazy images as input and proceeds by separating the color components. It also predicts the transmission map, guided filter, and atmospheric lighting depending on these components. The Type-2 Fuzzy-Set Edge detection approach is used for more precise and reliable identification. Details of our suggested technique are given in the next section.

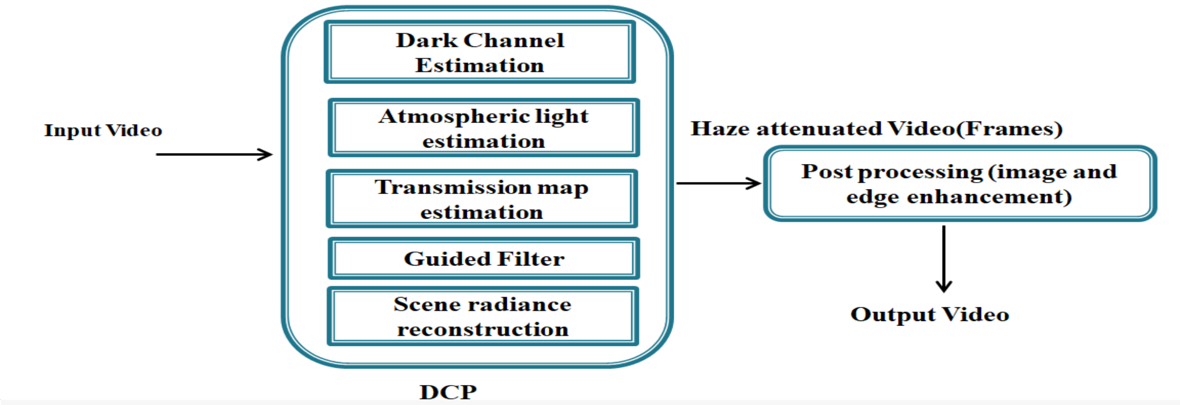

Fig 1: Block diagram of the proposed method

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3.1 DARK-CHANNEL PRIOR

Here, it is explained in relation to the equations used for the calculation of the haze level in an image. The dark channel of image I at a given pixel position x is the lowest pixel intensity in all RGB channels, as determined for each local window in the frame. In an image, it is provided by,

$$\square\; min_{y\in\omega(x)}(min_{c\in\{r,g,b\}} I^c(y)),\ \omega(x) \qquad [1]$$

Illustrating the window centered on pixel x.

The technique combines J^{dark}, a dark- channel of I, with Ic, a colour channel of I, and a local region surrounding the x-pixel to detect the ambient light. The algorithm uses J^{dark} to find the maximum 0.1% of the values of the pixels, as these is usually opaque and blurred, like in equation. Using the pixel of the maximum intensity to find the estimation of the air light may not be effective in case of the presence of an object of higher intensity than the air light. Therefore, the indices of the maximum 0.1% of pixels are stored in memory to be used later.

$$m = arg_{\tilde{x}} \max (J^{dark}\ (\tilde{x})) \qquad [2]$$

The summing of the values of the three color channels leads to an additivity of I: The pixel A corresponds to the maximum sum in the next figure.

$$A = arg_{\tilde{I}} \max (\textstyle\sum_{c\,\in\{r,g,b\}} \tilde{I}^c\ (m)) \qquad [3]$$

The dark-channel can be normalised using I and the predicted A in the following way:

$$J_N^{dark}(x) = min_{c\in\{r,g,b\}}(\frac{I^c(x)}{A^c}) \qquad [4]$$

It is considered that ~t is the coarse transmission.

$$\tilde{t}(x) = 1 - (\,\omega \times min_{y\in\Omega(x)} \left(J_N^{dark}(y)\right)) \qquad [5]$$

K. He [9] uses a factor of 0.95 to consider aerial view in their solution where is based on a very dense matrix of pixels. While Ke.Chen [8] employs an average-shift filter to successfully smooth non-coherent and noisy transmissions map.Although different techniques are used here, both approaches lead to almost the same result, in this paper, it's called the refined transmission map t in [3]. To determine J, modified transmission t and A are employed as follows:

$$J(x) = \frac{I(x)-\ A}{\max(t\ (x),t_0)} + A \qquad [6]$$

Accordingly K. He [9] has set t0 to 0.1 in locations where the transmission map value is less than 0.1 to prevent division by zero. The process of soft matting involves complex computations and requires a significant amount of memory. Hence, Ke.Chen [8] opts for selecting the minimum color channel value for every pixel to generate the dark channel. The estimation of A is carried out using Eqs. (2) and (3), and the transformation described in Eqs. (1) and (5) from [12] is also applied.

$$J^{dark}(x) = min_{c\in\{r,g,b\}}(I^c(x)) \qquad [7]$$

3.2 ATMOSPHERIC LIGHT ESTIMATION:

Employing a big local spot to construct the dark channel can yield a precise ambient light measurement. Using a second dark channel with a large local patch size to estimate ambient light is advised if the first one's size proves inadequate for creating the dark channel. It has been shown that local entropy works well to increase estimation accuracy by avoiding the estimation of ambient light from bright objects.

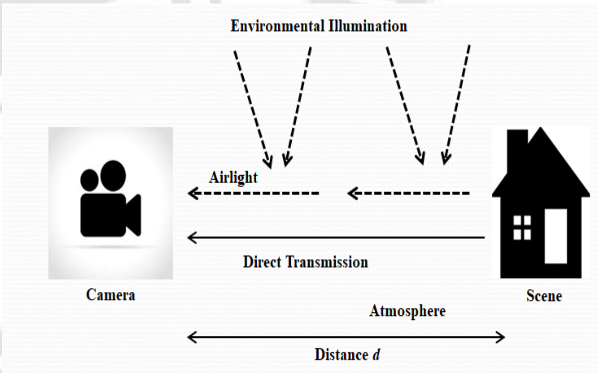

Fig 2: Light reflection from atmospheric particles

The following equation presents a model of atmospheric light scattering in computer vision, as has been presented by Shi et al. 2018, Kim et al. 2019, and Lee et al. 2020.

$$(p) = J(p)t(p) + A\,(\,1 - t(p)) \qquad [8]$$

where A is ambient light, R is the intensities at pixels p, J is the resulting picture, I is the initial picture, and t is a transmision maps.

3.3 Type-2 Fuzzy-Set

Type-2FS is utilized by researchers to overcome various problems and has been implemented in many ways. In fuzzy logic, the membership in a set can't always be binary as set theory predicts. Fuzzy logic is commonly used for the identification of image edges based on the division of the range of grey levels into three values representing the maximum entropy. Membership functions like the Gaussian and triangle functions are applied to convert from crisp to fuzzy values. Achieving high entropy is the ultimate focus by researchers in their fuzzy systems. These systems serve as threshold systems for edge detection and enhance the capacity to discern neighbouring pixel points. Rather than having a single, specific membership value, Type-2 FS has a range of feasible membership values. The output membership functions provide new areas for the image's

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grey levels, which facilitates the detection of grey levels in individual pixels.

3.4 Evaluation Metrics:

A quantitative analysis is carried out to evaluate the effectiveness of the recommended approach. Peak Signal to Noise Ratio, Structural-Similarity Index, Lightness Order Error, and Naturalness Image Quality Evaluator are some of the assessment metrics used in it. These measures assess the approach's quality and perceptual correctness. A quick explanation of such measures is provided below. Generally speaking, picture compression uses PSNR. It serves as a gauge for the rebuilt image's worth. The quality of the reconstruction improves with increasing value. The formula for PSNR is:
PSNR=10log10 (peakval2)/MSE,

In this case, "peakval" denotes the image's greatest intensity value, while "MSE" stands for Mean Square Error. The SSIM aims to capture the perception of damage in structural information, specifically where the pixels are spatially confined or interdependent. It is a method of measurement for quantifying the values of pictures and videos. SSIM measures the similarity between the original and the reconstructed images using:
$SSIM(x, y) = [l(x, y)]^{\alpha}. [c(x, y)]^{\beta}. [s(x, y)]^{\gamma}$
An order of lightness is relative and indicates the preservation of naturalness. The symbols l, c, and s indicate this order. These positive constants used in the calculation process are represented by α, β, and γ.

The analysis done proves that an relative-order of lightness is crucial for the naturalness of an image. The direction of the light source and the variations in luminance both has an impact on this order. Consequently, a better image's naturalness is determined by the relative brightness in different local locations. Additionally, the LOE measure is applied, which quantifies the difference between the original picture I and its better version I^e in terms of lightness order error. The greatest value of an image's three-color channel generates its level of brightness, which is expressed as L(x, y).

$$L(x, y)= \max_{c \in \{r,g,b\}} I^c(x,y) \quad [9]$$

For every pixel (x, y), the relative order difference in brightness between the original picture I and its improved version I^e is defined as follows:

$$RD(x,y) = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(U(L(x,y),L(i,j)) \oplus U(L_e(x,y),L_e(i,j))\right) \quad [10]$$

$$U(x,y) = \begin{cases}1, & x \geq y\\ 0, & else\end{cases} \quad [11]$$

The variables "m" and "n" are used in this study to represent the width and the height, respectively. Whereas "⊕" represents the exclusive-or operator, "U(x, y)" represents the unit step function. According to LOE, a lower value of LOE corresponds to a higher degree of lightness order preservation. The index used to assess the quality of genuine images is called the level of naturalness Image Quality Evaluator, or NIQE. It calculates the degree to which a picture resembles common nature scenes based on specific statistical characteristics present in real images. The no-reference image quality evaluation metric is called NIQE.

That is, it can be used to determine the quality of an image without necessarily using a high-quality reference image against which the quality of the image is gauged. The NIQE measure is determined using the following equation:

$$NIQE\sqrt{\frac{1}{N}x^2\sum_{k=1}^{N}\left(\frac{X_k-\mu_k}{\sigma_k}\right)^2}$$

A feature vector Xk is taken out of each of the N local patches that make up the picture. For each patch, the mean and variance of the feature vector Xk are represented by the symbols μk and σk, respectively. By comparing an image's local patches to its intrinsic statistical feature, NIQE assesses how comparable the two are statistically. Greater NIQE scores indicate lesser quality; lower NIQE scores indicate greater quality.

4. EXPERIMENTAL RESULTS

Experiments are carried out on datasets that are cloudy and blurred videos sourced from Kaggle. Figure 3 illustrates results of the proposed approach for sample video frames. The suggested method's efficacy in enhancing image quality and eliminating haze is quantitatively evaluated against the most advanced dehazing techniques available today.

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Fig 3: outcomes of the different methods with the proposed method

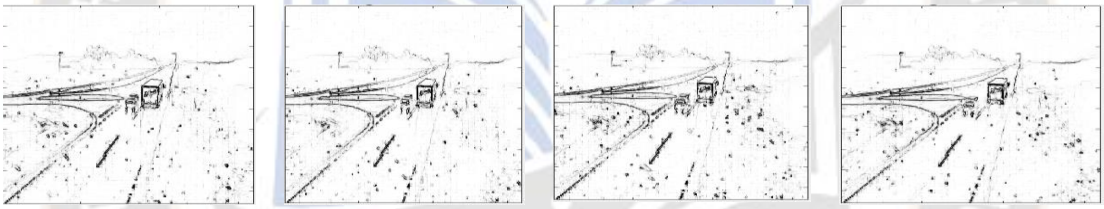

Fig 4: Results of Fuzzy edge detection

The findings are contrasted with the outcomes of the techniques put forward in the literature by K. He [9] and Ke Chen [8]. Figure 3 displays the PSNR and SSIM values based on the graphical findings of the chosen test pictures. Table 1 provides a detailed explanation of the findings and compares the suggested methodology with other methods that have been published in the literature.The discussion focuses on the execution time, PSNR, and SSIM values. Figure 5 depicts the graphical relationship between PSNR and SSIM values.

Table 1: Time evaluations of several methods

	Techniques		
Time (sec)	**K.He [9]**	**Ke.Chen [8]**	**Proposed algorithm**
Video 1	2.670994	3.681190	2.611389
Video 2	20.861764	22.221393	16.224129
Video 3	2.998437	3.871684	2.789405
Video 4	21.294896	22.952105	17.191658

Table 2: Evaluation of the Suggested Approach With Known Approaches in the Literature

Technique	**Video**				
		1	2	3	4
K.He [9]	PSNR	18.436454	19.490990	18.865732	17.426763

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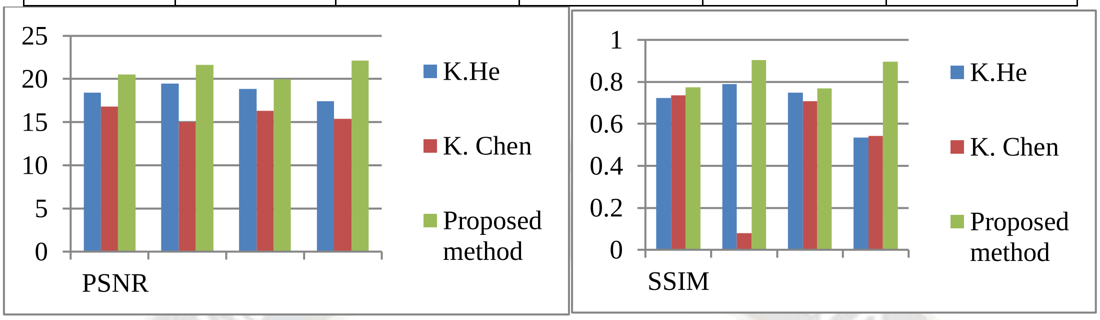
	SSIM	0.724157	0.788907	0.747425	0.535226
Ke.chen[8]	PSNR	16.791065	15.041182	16.325396	15.388243
	SSIM	0.735530	0.080182	0.708234	0.542127
Proposed algorithm	**PSNR**	**20.537813**	**21.613208**	**19.938537**	**22.123690**
	SSIM	**0.773762**	**0.903050**	**0.768758**	**0.896469**



PSNR Values **SSIM Values**

Fig 5: Evaluation of Methods Using PSNR and SSIM Quality Metrics

Our method's effectiveness was proven by the performance metrics of sample frames, which are detailed in Table 2. Implementation was done in MATLAB R2020a (8.1.0.430) running on a system with an Intel(R) Core(TM) i5-3230 CPU 2.60GHz, 4GB of RAM.

Table 3: Comparison of speeds for various approaches

Techniques				
Fps(ms)	1	2	3	4
K. He [9]	94.336986	81.978592	85.157217	28.160768
Ke. Chen[8]	56.771108	64.817721	55.261733	57.396132
Proposed algorithm	**17.402501**	**15.655858**	**14.921810**	**5.330516**

Table 4: Evaluation of Sample Videos Using NIQE and LOE Metrics

NIQE		LOE
Original video	Dehaze video	
3.5	**2.8**	**0.026**
3.0	**2.7**	**0.178**
3.5	**2.9**	**0.001**
4.0	**2.8**	**0.017**

The proposed technique effectively eliminates haze from input images while recovering intricate object details, leading to decreased brightness in the resulting frames. In particular, we employed Canny's widely utilized edge detection method for grayscale images and Type-2FS to automatically determine threshold values for gradient image segmentation in situations with insufficient lighting and hazy boundaries.

The efficacy of our algorithm in processing video frames, especially in edge detection assignments, was highlighted by the outcomes.

5. CONCLUSION

In conclusion, our methodology for video dehazing, combining DCP, Type-Fuzzy Sets, and Guided Filter, yielded improved visual quality of hazy videos. Performance metrics namely, PSNR, SSIM, NIQE, and LOE validate the effectiveness of the approach. By experimenting with and then interpreting these results, the program generates new and useful knowledge about the modes of operation and output quality of various haze removal and edge detection methods. Therefore, this program can be seen as a valuable asset to the discipline of image processing and computer vision, creating useful tools for increasing the apparent quality of images and enhancing their feature detectability under adverse conditions. Future lines of modifiability may include various improvements in edge detection such as more sophisticated ways of distinguishing false positives and negatives, the transformation of the process for real-time application, more adaptive haze removal algorithms, domain-specific applications, and enhanced end-user interaction systems.

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