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A review on various methods for dehazing images

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Abstract

In this paper, a literature survey was introduced to study of enhancing the hazy images , because most of the images captured in outdoor images have low contrast, color distortion, and limited visual because the weather conditions such as haze and that leads to decrease the quality of images capture. This study is of great importance in many applications such as surveillance, detection, remote sensing, aerial image, recognition, radar, etc. The published researches on haze removal are divided into several divisions, some of which depend on enhancement the image, some of which depend on the physical model of deformation, and some of them depend on the number of images used and are divided into single-image and multiple images dehazing model , therefore, the haze and its model were studied and the research and methods that dealt with the removal of haze were explained and detailed its advantage and disadvantage which is required for further study.

Keywords: Dark Channel Prior, image dehazing, image restoration, outdoor images , Aerosol, haze.

مراجعة للطرائق المختلفة لازالة الغبار من الصور

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المستخلص.

في هذه البحث ، تم تقديم مقال مراجعة لدراسة تحسين الصور المشوه بالغبار ، لأن معظم الصور الملتقطة في الظروف الخارجية لها تباين منخفض ، وتشوه لوني ، وذات رؤية بصرية محدودة بسبب الظروف الجوية بسبب وجود الضباب والدخان وغيرها من الملوثات . وهذا يؤدي إلى تقليل جودة التقاط الصور وهذه الدراسة لها اهمية كبيرة في العديد من التطبيقات مثل المراقبة والكشف والاستشعار عن بعد والصورة الجوية والتعرف والرادار وما إلى ذلك. تنقسم البحوث المنشورة حول إزالة الغبار إلى عدة أقسام ، بعضها يعتمد على تحسين الصورة ، وبعضها يعتمد على النموذج الفيزيائي للتشوه ، وبعضها يعتمد على نموذج الصورة – الصور المتعددة لازالة الغبار ، لذلك تمت دراسة ازالة الغبار ونماذجه و تم شرح الأبحاث والأساليب التي تناولت هذا الموضوع وتفصايلها ومزاياها وعيوبها. وهذة الدراسة تساعد الباحثين في الدراسات المستقبلية .

الكلمات المفتاحية: ازالة الغبار من الصورة , استعادة الصورة, الصور الخارجية, الهباء الجوي

Introduction

Images taken outdoors are often affected by several weather conditions that lead to distortion or reduce their quality, and this affects the programs that rely on these images taken because the image quality is reduced or distorted(Hashim, 2020). These images are used in several applications such as detection(Daway et al., 2018), surveillance(Meshram & Lande, 2018), remote sensing(Coppin & Bauer, 1996), aerial image, recognition (Razzak & Hashem, 2015), and radar. The atmosphere contains particles called Aerosols, which are either solid or liquid and cause distortion of captured images (Babu & Venkatram, 2020).these suspend particles dispersed are reflected and absorbed by light which changes the color and contrast of the image and leads to a degraded image. Examples of these aerosols are haze, dust, fog, smoke, rain, etc. (Nayar & Narasimhan, 1999; Zhu et al., 2015).Several studies were conducted to arrive at the division of these particles into types, as it was concluded that the number of these particles depends on whether fluctuations, as they were divided into steady and dynamic (Kaufman et al., 1997)(Singh & Kumar, 2018)as shown in table1, where in steady weather radius size of particles is approximately (1-10μm), fog, mist, and haze are example of steady weather, whereas radius of particles in dynamic weather is approximately (0.1-10 μm), rain and snow are an example of dynamic weather (S. G. Narasimhan & Nayar, 2002)

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Table (1) types of particles with its size associated with weather conditions

Weather condition	Type	Radius (μm) of particles
Haze	Aerosol	2-10
Fog	Water droplet	1-10
Air	Molecule	4-10
Rain	Water droplet	102-104
Cloud	Water droplet	1-10

Therefore, the process of removing haze is an important process to improve the quality of the image, which is used in several important applications that have already been mentioned in this research, we will discuss the methods and types of haze removal and mention the differences between them.

1- Haze model

The most famous model that used in the image processing field to describe the equation of haze image is(Rafid Hashim et al., 2022) (He et al., 2010):-

$$I(xi) = J(xi)\ t(xi) + A(1 - t(xi)) \qquad (1)$$

Where $I(xi)$ represent the observed intensity of the hazy image at xi position, $J(xi)$ act the scene radiance or the image that is intended to be restored at xi position, where $t(xi)$ act the transmission medium, A represents the atmospheric light. In the above equation (1) ($J(xi)\ t(xi)$) called direct attenuation which acts as the decay of the scene radiance in the medium and that leads to a decrease in the image contrast, while$(1 - t(xi)$ called airlight which acts as the scattered light and it leading to add whiteness of the image because of the shifting in the color image, figure (1) represents the formation of the haze model.

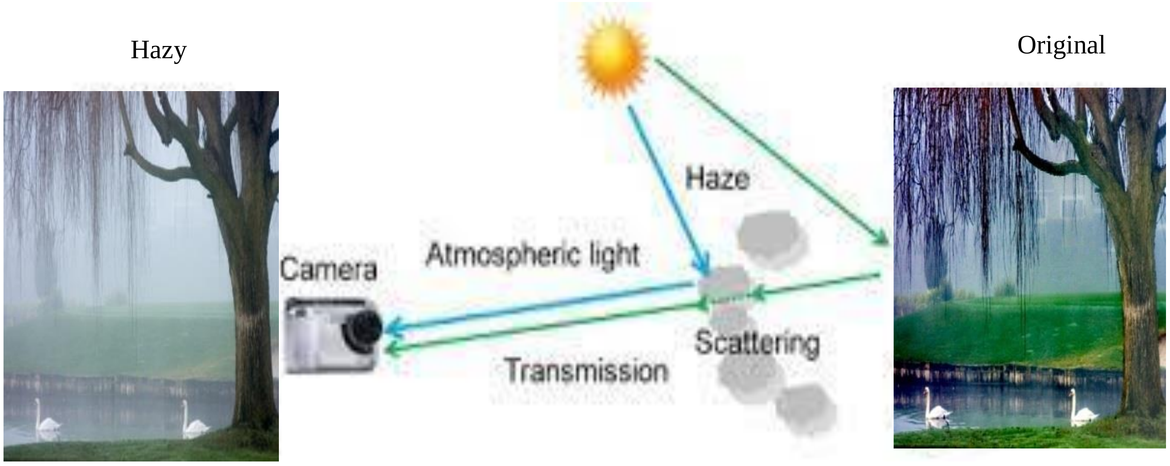

Fig (1) Formation of haze model

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2- Haze removal techniques

According to the research published on haze removal, there are several techniques for removing haze from the image, and these techniques are divided into several divisions, the most famous of which is divided into two divisions(Babu & Venkatram, 2020):

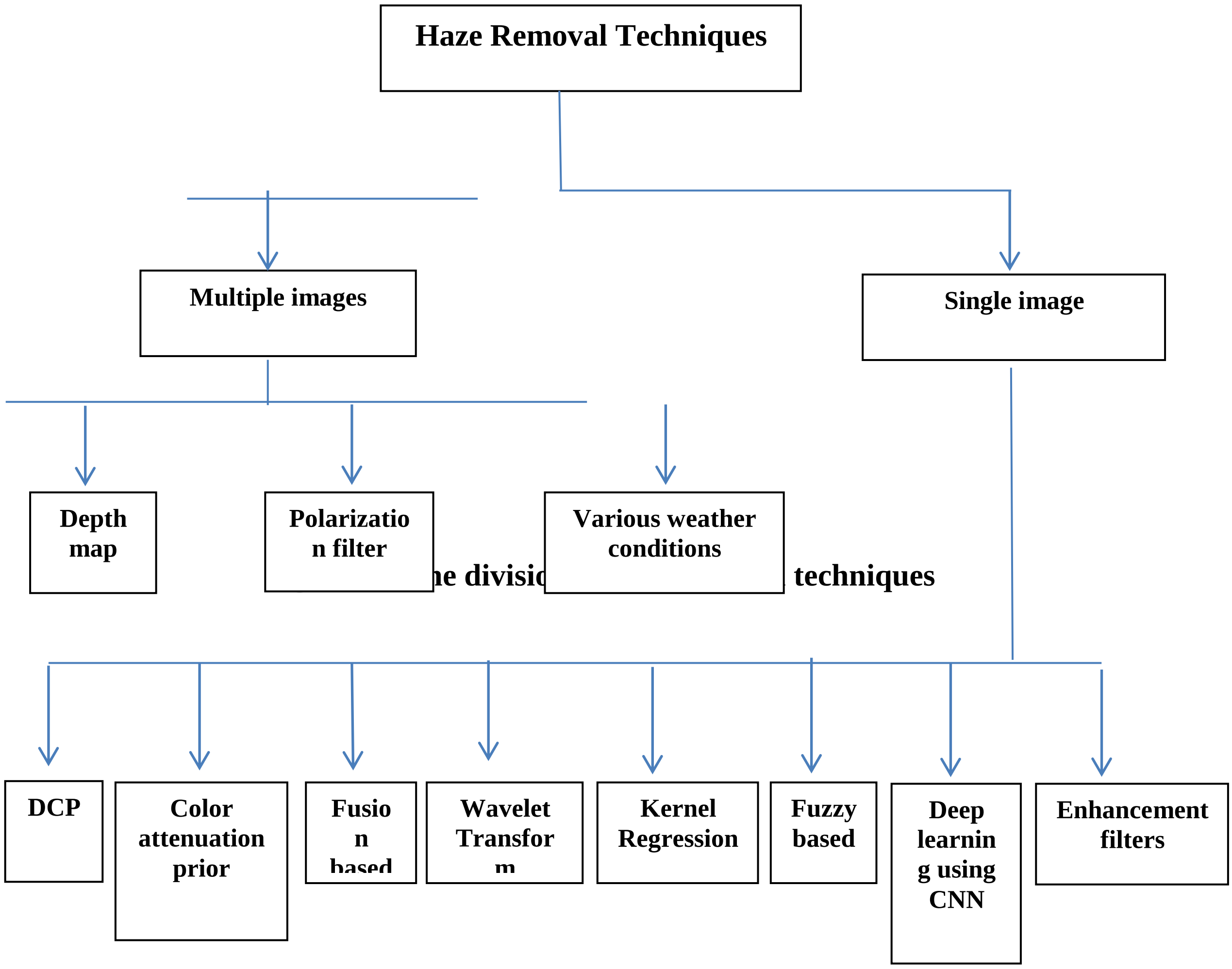
The first division is based on enhancement or based on the physical model. For this division, if it depends on the enhancement, then in this aspect it does not care about knowing the reason that if the image is distorted, it only cares about improving the image by enhancement contrast or removing noise, but these methods can lead to a loss of information, As for the enhancement based on the physical model, this method depends on building a distortion model, that is, building a model of haze for better retrieval of the original images.

The second division, this division depends on the number of images of the scene, and it is divided into single-image dehazing and multiple images dehazing(Senthilkumar & Sivakumar, 2019), as for single image dehazing this type needs one image of the scene, and this type depends on a statistical assumption which is the most used type in research to remove haze. It only needs one image of the scene and depends on building a distortion model to retrieve the image.

As for multiple images dehazing, this type depends on several images of the scene, either two or more images depending on various weather conditions (S. G. Narasimhan & Nayar, 2000; Nayar & Narasimhan, 1999)(S. G. Narasimhan & Nayar, 2003), or depending on polarization(Nayar & Narasimhan, 1999; Schechner et al., 2003; Shwartz & Schechner, 2006),(Schechner et al., 2001)or on death map (S. Narasimhan & Nayar, 2003)(Kopf et al., 2008).

Regarding various weather conditions by taking several images under different conditions, the method depends on taking the difference between two or more images of the same scene. This method can improve the images, but it also requires images of the scene with different weather changes and it cannot be applied to the scene simultaneously.

As for regarding polarization by taking two or more images of the same scene, but using filters to polarization to a different degree, one of the disadvantages of this method is that it cannot be applied to a dynamic scene in which the change is faster than the rotation of the filters, and this type needs special devices such as polarizer and sometimes does not provide satisfactory results. While for the death map this method uses depth information by using multiple images of 3D models of the scene to remove haze, one of the drawbacks of this method is that it is not automatic and requires user intervention to enter multiple parameters. We note that the method of multiple-image dehazing needs several inputs and contains many disadvantages, so most of the methods currently used to remove haze depend on single-image dehazing. These divisions and research related to the treatment of haze will be mentioned in the literature survey section. Figure (2) explain the division of haze removal techniques .



3- Literature survey

He et al.(He et al., 2010) presented a method to eliminate haze from a single image called Dark Channel Prior (DCP) derived from statistics of haze-free image, this method is simple, powerful, and produce good results, but this method has a disadvantage because it doesn't produce a good result in dehazing where the scene is near to atmospheric light also it produce halo artifacts in a dense haze. This method is compared with other methods using subjective assessment only.

Yang et al.(Qingsong et al., 2013) presented a method to eliminate haze from a single image. This method used DCP and histogram specification, first DCP was used to remove haze from the image and then enhance the contrast and intensity of the dehazing image to get a better result than using DCP only. This method compared with other methods using subjective assessment metrics depend on author evaluation depend on observes without using objective image quality metrics.

Fatal (Fattal, 2014) presented a method to eliminate haze from a single image. This method .this method used the color lines that exist in the natural image to obtain the transmission versus the existing dehazing method that depends on assumption across all image scenes. The disadvantage of this method is failed in dense haze or skylight, also this method show artificial color in the night

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scene. This method compares with other methods using accuracy for known ground truth, real image with the known transmission, and sensitivity to scattering and noise.

Dubok eta al.(D. Park et al., 2014) presented a method for dehazing a single image. This method used a quad-tree subdivision to get atmospheric light after preprocessing. Then used maximum value of the function consisting of image entropy and information fidelity to estimate the transmission, after that used Weighted Least Squares (WLS) as optimization for transmission. This method compared with other methods using image quality metrics such as colorfulness, global contrast factor (GCF), visible edge gradient, and mean ratio of the gradient.

Verma et al.(Verma et al., 2017) Introduced a method to eliminate haze from a single image. This method converts the entire image into an HSV color model then enhance the V component by using histogram equalization while applying DCP on chrominance components (H, S and V) then converts it into an RGB model to get dehazing image. this method is compared with other methods using image quality metrics such as PSNR, MSE, Maxerr, and entropy.

Salzar et al.(Salazar-Colores et al., 2018) presented a method for dehazing a single image. This method used Multilayer Perceptron (MP) in estimating the transmission instead of the equation of transmission estimation in the DCP method to get rid of computational time; it used 80 real haze images to train the MLP to obtain transmission and transmission results. This method is compared with other methods using image quality metrics such as PSNR and MSE.

Cameron Hodges et al.(Hodges et al., 2019) presented a method for dehazing a single image by using a deep Computer Neural Network(CNN) this method consists of two networks that are dehazing network by dividing the entire image into 589 patches (20x20x3) to estimate transmission for each patch, then compute transmission map and atmospheric light (A) for the entire image to get a clear image, the result of this network will enter into discriminator network which benefits to make the network difference between the haze image or clear image even if the content is not matched. This method is compared with other methods using image quality metrics such as PSNR and SSIM.

Yutaro Iwamoto et al.(Iwamoto et al., 2018) introduced a method for dehazing a single image. This method depends on improving the DCP method by making it consume less computational time by using down sample and don't need soft mating. This method is compared with other methods using subjective observation by humans and compared in time consumption.

Codruta O.Ancuti et al.(C. O. Ancuti et al., 2019) introduced a new database containing 33 pairs of dense haze images and ground–truth images, then applying some of the existing dehazing methods on this database such as he et al (He et al., 2010), meng et al(Meng et al., 2013), fatal (Fattal, 2014), Cai et al.(Cai et al., 2016), Ancuti et al(C. Ancuti, Ancuti, De Vleeschouwer, et al., 2016), Berman et al(Berman & Avidan, 2016), and Ren et al(Ren et al., 2016) . Then the authors compared these methods using subjective evaluation depending on visual results and also compared these methods using image quality metrics such as PSNR, SSIM, and CIEDE2000(Sharma et al., 2005). This

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method introduced the conclusion that the existing dehazing method introduced low performance in a dense haze.

Asem Khamg et al(Khmag et al., 2018) presented a method for dehazing a single image. This method consists of two parts, the first part estimate the transmission map using the mean vector L2-norm while the second part is enhancing the transmission map using the second generation of the wavelet transform. This method is compared with other methods using no-reference image quality such as visible edge rate, average gradient rate, and information entropy.

Shengdong Zhang et al (S. Zhang et al., 2020) presented a method for dehazing a single image. depend on new deep learning methods using CNN. This method first estimates the transmission map by joint detail of clear image and transmission map of haze image, then eliminates halos and artifact effect by using the global regularization method. This method was applied to real word image, and synthetic data set and compared with other method using image quality metrics such as PSNR and SSIM.

Ahmed et al (Hashim, 2020)presented a no-reference image quality assessment for hazy images depending on the probability of saturation. This method compared with other methods by using correlation coefficients like Pearson Correlation Coefficient (PCC), Spearman Correlation Coefficient (SCC), and Kendall rank correlation. The result shows this method achieves a high value of correlation between objective and subjective assessment.

Lirong Li et al. (L. Li et al., 2017) introduced a method for dehazing a single image. This method depends on the imaging model under atmospheric scattering to estimate the transmission; also this method presents an estimation method for global atmospheric light. The disadvantage of this method it may fail in dense haze images. This method is compared with other methods using image quality metrics such as standard deviation, entropy, and an average of the gradient.

Zhu Rong and Wang Li Jun (Rong & Jun, 2014) introduced a method for dehazing a single image. This method depends on using wavelet transform to remove haze and then using Single Scale Retinex (SSR) for improving color and improve the color effect.

Z.Wang and Y.Feng (Wang & Feng, 2014) introduced a method for dehazing a single image. This method depends on the DCP method for removing haze then used fast wavelet transform are used to enhance DCP. the transmission map is estimated using two steps one is estimated based on single-point pixel and the other is estimated based on the patch then two-part are fused, then enhanced the contrast of result using sigmoid function adaptively. This method is compared with another method in terms of execution time and visual effect.

Jin-Hwan Kim et al (Kim et al., 2013) introduced a method for real-time image and video dehazing. This method consists of many steps beginning from using quad tree-based subdivision to select atmospheric light then determine transmission value according to scene depth, then enhance the contrast of the hazy image and decrease the loss of information due to enhance contrast by using minimizing a cost function. This method is compared with other methods using subjective assessment.

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Yong –Qin Zhang et al (Y.-Q. Zhang et al., 2012) introduced a method to enhance the contrast of dehazing image. This method work on enhancing the resulting image from DCP dehazing method by using the low-rank technique and the overlapping average scheme. This method is compared with other methods using subjective assessment and object metrics such as visible edges, mean ratio, and entropy.

Irfan Riaz et al (Riaz et al., 2016) introduced a method for dehazing a single image and reducing the disadvantage of the DCP method. This method improved the accuracy of block-level and pixel-level dark channel and generate a reliability map that was used to fusion both block-level and pixel-level dark channel to get a high-quality transmission map. This method reduces the disadvantage of DCP and the halo effect by increasing the patch size and preserving the edge, also reducing the pros of DCP in manipulating the sky region. This method is compared with other methods using image quality metrics such as MSE, and SSIM.

Zhongli Ma et al (Ma et al., 2016) introduced a method for improving the visibility of sea fog images using a fusion strategy. This method consists of third steps. The first fusion process used simple linear transformation to get the first input image, while the second step used guided image filtering to improve the high-boost filtering algorithm to get the second input image. The third steps include fusing the two image of step one and two. This method is compared with other methods using subjective and objective image quality assessment.

Qingsong Zhu et al (Zhu et al., 2015) introduced a method to remove haze from a single image. This method builds a linear model to get a depth map this model depends on color attenuation that is based on the difference between brightness and saturation, then used the supervised method to train, the resulting parameters used to get a depth map so transmission and scene radiance can be estimated. This method is compared with other methods using image quality metrics such as SSIM, and MSE.

Cong –Hua Xie et al(Xie et al., 2017) introduced a method to remove haze from a single image. This method uses DCP to remove haze and get transmission, then used Kernel Model (KRM) to eliminate the disadvantage of estimated transmission such as unsmooth and loss of neighbor information. The method was applied to a synthetic and real image. This method is compared with other methods using image quality metrics such as SSIM, and MSE.

Geetanjali and Seevia Baghla (Geetanjali and Seema Baghla, 2017) introduced a method to remove haze from a single image. This method uses DCP to remove haze and get transmission, then uses a genetic algorithm to select the best parameter to obtain optimistic results, this method is compared with other methods using PSNR and MSE image quality metrics.

Hasil Park et al (H. Park et al., 2017) introduced a method to remove haze from a single image. This method used fuzzy membership function to estimate transmission, then used l1- norm regularization to refine transmission, and after that used the refined transmission to get dehaze image from the haze model. This method is compared with other methods using CNR, NIQMC, and entropy image quality metrics.Table (2) explain the comparison of several haze removal technique

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Table (2) Explain the comparison of several haze removal technique

Reference	year	Authors	Techniques	Advantage	Disadvantage
(He et al., 2010)	2010	He et al	Dark Channel Prior (DCP)	Simple, powerful, and produce good results	Produce halo artifact in dense haze
(Qingsong et al., 2013)	2013	Yang et al	DCP and histogram specification	Powerful in remove haze also enhance the image contrast	Using only subjective assessment without objective image quality metrics
(Fattal, 2014)	2014	Fatal	Color lines (CL)	Obtain transmission using CL without need assumption across all image	Produce artifact in night scene and failed in dense haze, sky light
(D. Park et al., 2014)	2014	Dubok et al	Quad –tree subdivision, objective function, and WLS optimization	Success in enhanced image contrast and keep color of image	Complex
(Verma et al., 2017)	2017	Verma et al	DCP and histogram equalization	Success in enhance illumination of image	May produce halo artifact in dense haze
(Salazar-Colores et al., 2018)	2018	Salazar et al	Multilayer perceptron (MP) to estimated transmission	Reduce computational time of transmission estimation	Used only reference image quality metrics without no reference image quality metrics
(Hodges et al., 2019)	2019	Cameron Hodges et al	Deep Computer Neural Network (CNN)	Processing speed in training and testing CNN	Using only objective assessment without subjective assessment
(Iwamoto et al., 2018)	2018	Yutaro Iwamoto et al.	Improving DCP using down sample	Consume less computational time	Using only subjective assessment without objective image quality metrics
(Khmag et al., 2018)	2018	Asem Khmag et al.	Mean vector l2-norm and second generation of wavelet transform	Preserving of edge and fine texture	Used only objective image quality assessment and not used subjective image quality assessment

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Table (2): (continued)

Reference	year	Authors	Techniques	Advantage	Disadvantage
(S. Zhang et al., 2020)	2020	Shengdong Zhang et al	CNN	Eliminate of halo and artifact effect	Using only reference image quality assessment without using no-reference image quality assessment
(L. Li et al., 2017)	2017	Lirong li et al.	Imaging model under atmospheric scattering	Simple and powerful	May fail in dense haze image
(Wang & Feng, 2014)	2014	Z.wang and Y.feng	DCP , fast wavelet transform and sigmoid function adaptively	High speed in enhance image	Used only visual effect in comparison with other methods
(Kim et al., 2013)	2013	Jin- Hwan Kim et al.	Method consist of many steps for real image and video dehazing	Enhance the contrast and decrease information lossing	Used only visual effect in comparison with other methods
(Y.-Q. Zhang et al., 2012)	2012	Yong-Qin Zhang et al.	Low rank technique and overlapping average scheme	Work on enhancing the result image from DCP	May be fail in dense foq and produce halo
(Riaz et al., 2016)	2016	Irfan Riaz et al.	Fusion both block level and pixel level dark channel	Reduce halo effect and preserving edge	Not used no-reference image quality assessment
(Zhu et al., 2015)	2015	Qing Zhu et al.	Supervised method	Efficiency in removing haze	Not used no-reference image quality assessment
(Xie et al., 2017)	2017	Cong- Hua Xie et al.	DCP and kernel model (KRM)	Eliminate the disadvantage such as un smooth and losing neighbor information	Not used no-reference image quality assessment
(Geetanjali and Seema Baghla, 2017)	2017	Geetanjal and Seem Baghla	DCP and Genetic Algorithm (GA)	GA is used for better visualization of image and select the best parameters	Not used no-reference image quality assessment
(H. Park et al., 2017)	2017	Hasil Park et al.	Fuzzy set theory and L1-norm regularization	Reduce halo artifact and color distortion	Used only objective image quality assessment

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4- Image quality metrics

Image quality metrics are used to measure the performance of haze removal methods. These metrics are divided into two types depending on the availability of the reference image, as shown in figure (3).

5.1- when the reference image is available

In this situation, the ground truth image or reference image is available for the same haze image. This case uses to estimate the quality of haze removal methods image when the reference image is available as a hazy image database. Many quality metrics can be considered such as Mean Squared Error (MSE), Structure Similarity Index Metric (SSIM), and Peak Signal to Noise Ratio (PSNR).

5.2- when the reference image is not available

In general, the reference image is not available, so it is difficult to estimate the quality of haze removal methods depending on a comparison between the reference image and dehaze image, many quality metrics can be considered such as Average Gradient (AG), entropy, mean of local standard deviation, and mean of image.

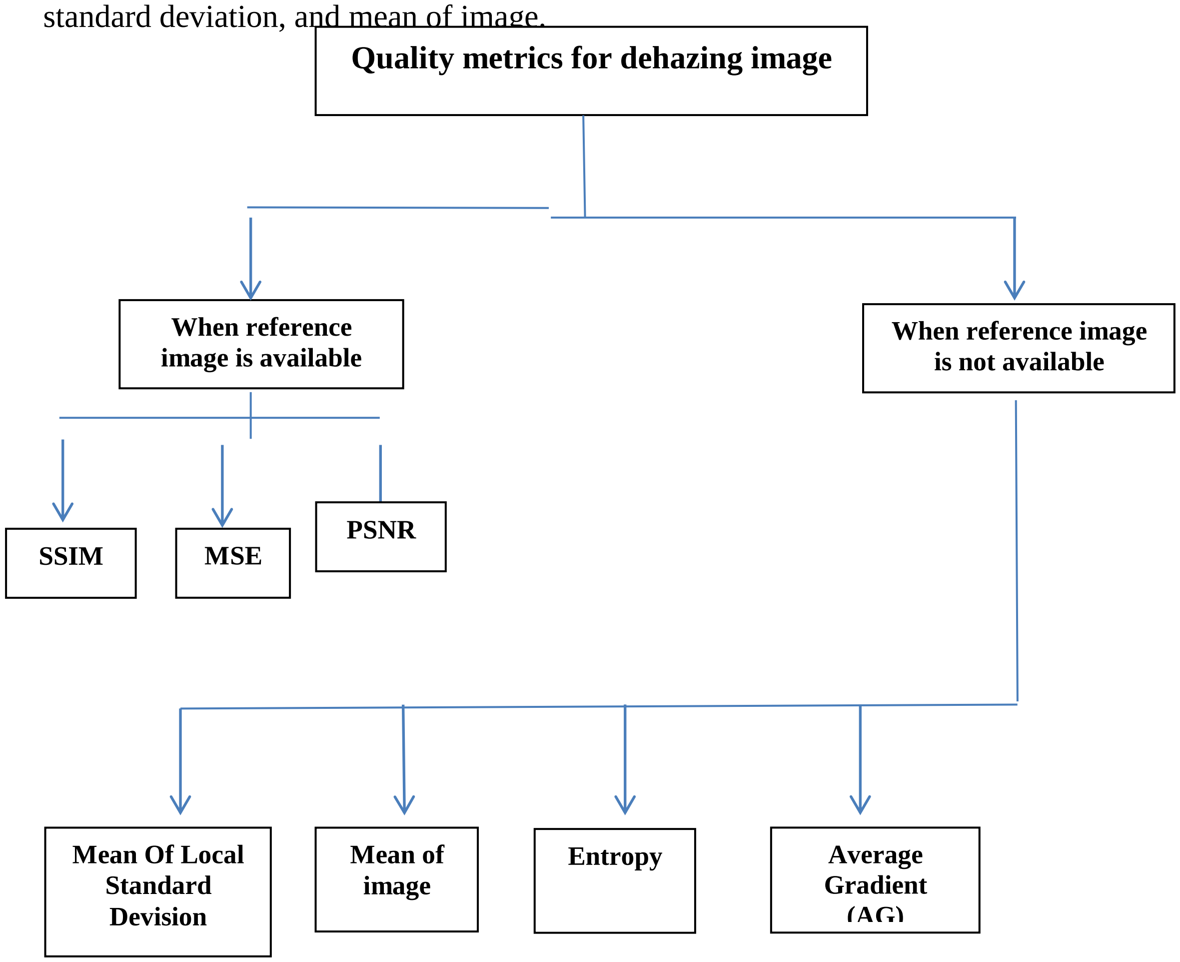

Figure (3) Flowchart for quality metrics of dehazing image

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5- Haze image database

Many databases provide images of haze for researchers to study and compare methods of haze removal. Most of the existing databases contain haze images and reference images (haze-free images) and this provides subjective and objective assessment.

There is a database that contains only haze images and does not contain ground truth images such as FADE (Choi et al., 2015)

Also there are several databases that contain haze image in addition to ground truth image, such as Frida (Tarel et al., 2010)(Tarel et al., 2012), middle-bury(Scharstein et al., 2014) , Nyu-v2 (Silberman et al., 2012), I-Haze (C. Ancuti et al., 2018), 3D dataset(Saxena et al., 2008), Chic dataset (El Khoury et al., 2018), O-Haze (C. O. Ancuti et al., 2018) , D-Haze(C. Ancuti, Ancuti, & De Vleeschouwer, 2016) , Haze RD (Y. Zhang et al., 2017), dense haze (C. O. Ancuti et al., 2019),and reside (B. Li et al., 2018).

The presence of ground truth images enables researchers to work and evaluate methods for removing haze by subjective and objective assessment.

6- conclusion

In this research, the haze was studied and methods of haze removal were discussed due to the importance of this topic in several applications in life, and we conclude through these methods and research that most methods of haze removal depend on removing the haze is a complex process due to the need for a depth map, and the most important thing in retrieving the image after removing the haze is that the retrieval of lighting and colors is efficient while preserving the colors. This research is not to evaluate previous studies but to provide a reference

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