Enhancement Algorithms for Low-Light and Low-Contrast Images

Snežana Puzović, Ranko Petrović, Miloš Pavlović, Srđan Stanković
Vlatacom Institute
Belgrade, Serbia
snezana.puzovic@vlatacom.com; ranko.petrovic@vlatacom.com; milos.pavlovic@vlatacom.com; srdjan@vlatacom.com

Abstract— **Images in bad weather can be degraded by scattering atmospheric particles, and suffer from low contrast and faint color. Main focus of this work is on dehazing methods that can be used for low-light and low-contrast conditions. Dehazing algorithms can be applied to low-light (night) imaging in a way that inverted night images are considered as hazy images. Different image quality metrics are used to measure quality of image enhancement algorithm. Since it is not easy to obtain original image without haze, special attention is given to the no-reference metrics that evaluate image contrast enhancement.**

Keywords - Image dehazing; Low-light Imaging; Image Enhancement; Image Quality Assessment.

I. INTRODUCTION

Video-enhancement algorithms in long-range surveillance systems are important topic recently. Image enhancement system setup used in this paper is based on Vlatacom Multi-Sensor Imaging System (vMSIS2), second generation [1]. The vMSIS2 is a state-of-the-art monitoring and surveillance system that integrates visible and infrared imaging sensors and provides ultra-long-range target detection, object recognition and identification.

Imaging sensors included in this type of systems are usually color (low-light), Thermal (Medium Wavelength Infrared – MWIR and Long Wavelength Infrared – LWIR) and Short Wavelength Infrared (SWIR) imaging sensors. Thermal and SWIR imaging sensors have the grayscale output and are not very prone to the haze problem, while color imaging sensors are very sensitive to this type of visual obstacles, and cannot be enhanced only with the well-known image enhancement techniques (like contrast adjustment), that are successfully used for grayscale images.

Long range surveillance systems are designed to detect various objects at very large distances (more than 20 km), where the influence of various atmospheric disturbances is very high. Bad weather conditions and presence of haze, dust, smoke, fog influences visibility of the scene, reduces contrast and obscuring information. In such circumstances, the most of the visual information could be lost.

High-visibility images reflect clear details of target scenes, which is very important for applications of object detection and tracking that are present in vMSIS system. Images captured in low-light conditions are often of low visibility, with important information covered in dark. This leads to performance degradation of algorithms that are primarily designed for high-visibility.

Color imaging sensors are very sensitive to visual obstacles, such as scattered atmospheric particles. The role of dehazing process is to eliminate influence of weather conditions, to improve the visual state of the image and provide benefit for the next steps of post-processing. Night imaging conditions, usually with low visibility and with important information obscured, display very little of scene information. Scene depth influence on scene visibility - far objects are more obscured than near objects.

In this paper, we propose a novel, easy and yet effective way to enhance quality of low-lighting video obtained from color camera. Low-light enhancement algorithms presented here, relies on dehazing methods described in our previous works [2][3]. We presented and compared two dehazing algorithms that are often used in literature are compared their effectiveness using objective quality metrics. After inverting the low-lighting video, dehazing algorithms could be used to improve image quality in low-light conditions. Also method based on adaptive histogram adjustment is proposed for low-contrast imaging obtained from the system.

Image quality metric suitable to measure the performance of the algorithms for night (low-light) and low-contrast are presented in the following sections.

It is important to emphasize, that image enhancement should be adequately evaluated, so we did a research through a literature and selected several no-reference objective quality metrics suitable to evaluate image enhancements. Increasing number of works about objective image quality metrics tells us that it is very important and subjective impression of image enhancement is not enough [10][13][15][17].

No-reference quality metrics [4] that were primary adopted for the infrared imagery (images from SWIR and MWIR cameras), are used here to measure the contrast improvement of low-light color images when dehazing algorithm is applied on them. Additionally, two commonly used no-reference quality metrics, suitable to evaluate performance of image dehazing algorithms for color images are applied[13][15].

There are many approaches to image dehazing process in the literature and we considered most important of them such as Dark Channel Prior (DCP) [5] Color Attenuation Prior (CAP)

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[6] and Dehaze Net (DNET) [7]. In this work we will apply DCP [5], and CAP [6] algorithms on inverted low-light images in order to improve quality of video sequences, and will measure performance of these algorithms with objective quality metrics.

Approach in [5] DCP is based on certain statistics of haze-free outdoor images - the authors assume that in most of the image local regions which do not cover the sky, very often some pixels have very low intensity (close to zero) in at least one of the RGB color channels.

Authors in [6] CAP developed model that constructs a linear relationship between the scene depth and the hazy image, difference between brightness and saturation can approximately represent the concentration of haze. Parameters of the model learned by a supervised learning method.

The paper is organized as follows. Section II describes two different dehazing algorithms, and Section III proposes most suitable image quality metric that measures objective quality improvement. Section IV and Section V describe the experimental work including the experimental setup, results and discussion. Section VI lists conclusions and indicates directions for future work in this research area.

II. Dehaze Imaging

A. Dehazing Enhancement for Low-Light Imaging

Wide class of dehazing algorithms is described with the well-known imaging equation [5], [6], [7]:

$$I(x) = J(x)t(x) + A(x)(1 - t(x)) \quad (1)$$

Where I is hazy image, scene radiance is J, thickness of haze t, and atmospheric light A.

Three main components of the dehazing algorithm are:

- The transmission map estimator computes t in the haze imaging equation (1).
- The atmospheric light estimator calculates A in haze imaging equation (1).
- The haze-free image generator generates the haze-free image J based on the estimated t and A.

Low-light imaging and haze imaging are based on the same principle, and here, we precise how dehazing algorithm should be adjusted. Low-light enhancement applies similar approach and algorithm is based on low-light image property, that inverted low-light image resembles, statistically, image with haze (darkness becomes haze in inverted image), so inverted low-light images are considered as hazy images.

In the literature [8] is used principle of inverting low-light video, and the resulted videos look very much like videos acquired in hazy lighting conditions. After inverting, the pixels in the sky and distant background regions of the inverted video always have high intensities in all color (RGB) channels but those of non-sky regions have low intensities in at least one color channel, similar to the case of video captured in hazy weather conditions.

Input low-light video frame *I(x):*

$$R^c(x) = 255 - I^c(x) \quad (2)$$

Where c is color channel RGB. $I^c(x)$ is intensity of color channel of pixel x, $R^c(x)$ is the intensity of inverted image.

Inverted results ***R*** from the input low-light video seq. 1, for two different dehazing approaches DCP and CAP can be seen on fig. 1 and fig.2.

The critical step [2] [3] in dehazing is calculating ***A*** and ***t(x)*** from ***R(x)***, and to recover ***J(x)***. We used two transmission map model defined in [2][3][6], the first one based on the DCP approach:

$$t(x) = 1 - \min_{y \in \emptyset(x)} \left(\min_{C} \frac{R_C(y)}{A_C} \right) \quad (3)$$

The second one is based on the linear model for the scene depth, CAP approach [5], and calculates the transmission map based on the linear coefficients ω_0, ω_1 and ω_2, the value of saturation and value channel:

$$t(x) = \exp(-\beta(\omega_0 + \omega_1 v(x) + \omega_2 s(x))) \quad (4)$$

Value for is $\beta = 1.0$, *v(x)* is brightness component, while *s(x)* is saturation component HSV color space.

ω_0, ω_1 and ω_2 are determined using supervised learning method. With the recovered depth information, the haze can be removed from a hazy image on the basis of the haze imaging model.

Atmospheric light A in (3) is calculated as in [2] [3], top 10% of the brightest pixels in the transmission map t(x) are picked, then the algorithm calculates the median value of the pixels in the corresponding hazy image *I(x)* among these brightest pixels (on t(x)), and it is considered as the atmospheric light A. To recover haze-free image J(x), next formula is used, where t(x) is restricted to t0(x) = 0.1 to avoid noise

$$J(x) = \frac{R(x) - A}{\max\{t(x), t0\}} + A \quad (5)$$

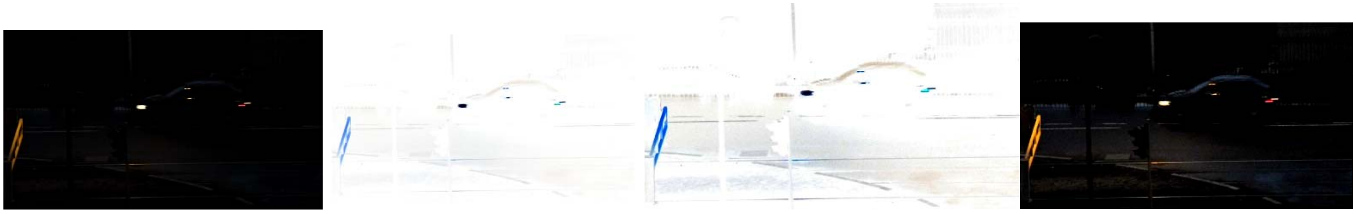
For low-light video, once *J(x)* is obtained, the inverted operation in (2) is done to produce the enhanced image of the original input low-light video frame. This process reduces dark covering the objects of interest on the image, with great value of restoring visibility.

Matlab 2018b software tool implementations of both dehazing algorithms, as well as objective (non-reference) quality metrics.

For the purpose of proposed low-light enhancement algorithm evaluation, two color camera footages (video seq. 1 and video seq. 2) containing 1000 frames per each are obtained with vMSIS2 system [1] described previously. Frame resolution is 1920x1080 pixels. Results of the low-light enhancement with two different approaches are given on fig 3. and fig. 4.

(a) (b) (c) (d)

Figure 1. Low-light video seq. 1 (a) Original, (b) Inverted *R* low-light image, (c) Dehazed output *J* using eq. 3, DCP algorithm(d) Final output *E* after inverting image *J*.



(a) (b) (c) (d)

Figure 2. Low-light video seq. 1 (a) Original, (b) Inverted *R* low-light image, (c) Dehazed output *J* using eq. 4, CAP algorithm, (d) Final output *E* after inverting image *J*.

Figure 3. Low-light image enhancement results video seq. 1 taken from distance of 50m: original (left), DCP enhancement (middle), CAP enhancement (right)

Figure 4. Low-light image enhancement results video seq. 2 taken for distance of 80m: original (left), DCP enhancement (middle), CAP enhanced image (right)

Additional image enhancement techniques could be used independently of dehazing enhancement algorithm, to improve quality of images that suffer from blur, haze, low-contrast and noise, and can be used within any of them. All such steps can be used within any of the existing dehazing approaches:

Contrast adjustment – The haze in the image is usually manifested by light regions with high saturation, which makes the contrast very low. Although dehazing helps in solving this, additional contrast adjustment of a color image is performed in the following manner – in all three color channels (RGB) of the image, the bottom 1% and the top 1% of all pixel values are saturated. This operation increases the contrast of the output image.

Median filtering – Hazy images also suffer from the presence of noise that remains on image in a certain amount, and can even be amplified after applying dehazing procedures. Median filtering is performed on all three color channels (RGB) of the image, in two dimensions. Each output pixel contains the median value of 3-by-3 neighborhood around the corresponding pixel in the input image. This operation removes the noise and makes the output image smoother than input image.

Image sharpening – The common problem related to hazy images that cannot be resolved very well with dehazing approaches is connected to blurred objects. Presented video enhancement algorithms include the unsharp-mask method as an additional sharpening technique incorporated in the dehazing procedures [9].

B. Low-Contrast Imaging

Vlatacom low-contrast imaging enhancement includes adaptive histogram redistribution, with the goal to be more haze-free conditions like, and to cover a wide range.

Histogram on images with severely reduced contrast in Vlatacom low-contrast imaging enhancement algorithm is redistributed per predefined histograms, that best describes the environment the sensing sensor is placed in.

The following figure shows information retrieval from image with severely degraded histogram. The resulting image suffers from noise, but it contains useful information, that was obscured in original image.

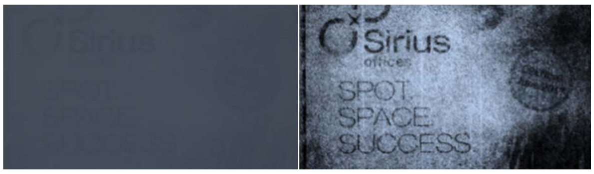


Figure 5. Severe low contrast taken from 600m distance: original (left), enhanced (right)

III. Image Quality Assessment

Image quality assessment (IQA) is a fundamental step in image dehazing [10]. Objective quality metric are needed to quantify the real enhancement of the image. In this work, objective quality evaluation methods are used. These methods can be divided in three categories: full-reference (FR), reduced reference (RR) and no-reference (NR), or “blind” quality assessment approach, depending on the requirement for the reference image. Since it is not easy in our case to obtain a reference image, NR quality assessment methods are used.

Here NR quality metric are used, based mainly on image contrast evaluation as we used for infrared imagery in [4]. Additionally we found two NR metrics that are suitable for assessment of dehazing algorithms and used in literature [10][13][14][15] and are presented in following text.

Results for objective quality metrics are obtained using Matlab software.

A. Visible Edges Based Method

Another NR quality assessment approach based on the contrast evaluation is the Visible Edges Based Method [12], used for dehazing effect evaluation. The method computes the ratio between the gradient of the visible edges for the image before and after contrast restoration, with the aim to increase contrast without saturation and, thus, losing some visual information.

The method evaluates the contrast enhancement details between an original and enhanced image with three indexes:

- e (the rate of new visible edges after enhancement),
- r (the ratio of the gradient of the visible edges before and after enhancement) and
- δ (the ratio of saturated (black or white) pixels after enhancement), given by

$$e = \frac{n_r - n_0}{n_0} \quad (7)$$

$$\bar{r} = exp(\frac{1}{n_r}\sum_{P_i \in \varphi_r} log r_i) \quad (8)$$

Where n_0 and n_r denote respectively numbers of the visible edges in the original image I_0 and in the enhanced image I_r, φ_r is the set of visible edges in I_r, P_r denotes the pixels that belong to the visible edge of image I_r, r_i is the ratio of the Sobel gradient P_i at the images I_r and I_0,.

The value of e evaluates the ability of the enhancing method to restore edges which were not visible in original image, but are visible in the enhanced image. Note that value of e may be even negative in case where the original image is enhanced over certain extent. Although there are more visibility pixels, these pixels connect together which make the visibility edges become less [16]. The contrast descriptor e computes the visible edge in gray-scale image.

The value of r expresses the quality of the contrast restoration by the proposed method, and this descriptor takes both invisible and visible edges in the calculation and it rates the average visibility enhancement. The contrast descriptor r focuses on enhancement of gradient value which produces more reasonable evaluation results on contrast enhancement.

Good results of image enhancement are described by high values of e and r and low values of δ. Image enhancing techniques are very often evaluated with these three parameters, and the expected values for e are in the range 0.1-0.5.

The minimum value for r is 1, and the expected values in the case of the dehazing algorithms are in the range 1-5 as we can see in [13], [14].

B. Fog Aware Density Evaluator

Fog Aware Density Evaluator (FADE) is descriptor of contrast. It can predict the visibility of the foggy scene, by measuring deviations from statistical regularities in natural scene foggy and fog-free images [15]. The method extracts 12 fog-related features from the test image, and uses *Multivariate Gaussian* (MVG) model. Then, it computes the deviation using a Mahalanobis-like distance between the MVG fit of the test image and the MVG fit of a corpus of 500 fog-free images and another corpus of 500 foggy images, respectively. A lower value of FADE implies better performance of visibility enhancement. It performs well for measuring the fog residue of dehazed image. Values of this metric are varying from 0 – 0.6 in the literature.

C. Contrast Colorfulness Naturalness (CNC) index

The CNC measurement system is proposed in [13], evaluates effects of dehazing using three parameters:

- ***e*** contrast (the rate of visible edges) rates visible edges in gray-scale image
- *Color Naturalness Index* (**CNI**) is the degree of conformity between human perception and reality world, the bigger the value of CNI is the more natural the color image is.
- *Colorfulness Index* (**CCI**) represents color vividness degree. It is defined as the summation of average saturation and standard deviation of saturation of the test image.
- ***CNI*** and the ***CCI*** are obtained from the dehazed image. Finally, a comprehensive evaluation function is constructed using e, CNI and CCI, and the restoration performance of each dehazing method is evaluated objectively and quantitatively.

$$CNC = e^{1/n_1} CNI + CCI^{1/n_2} CNI \quad (9)$$

In our analysis $n_1=1$ and $n_2=2$ are used [14]. According to [13] values of CNI are 0-1, while and CCI 16-20. Results in [13] show that CNC index for images with haze are in range 0-2, while dehazed images have values between 0.5 – 6.

D. Contrast Evaluation

In some articles [11] the contrast of an image is used as a metric for objective evaluation to verify improvements. Contrast can be expressed as:

$$C = \frac{1}{n}\sum_{i=1}^{n} \frac{max(i)-\min(i)}{\max(i)+\min(i)} \quad (10)$$

Where C is the average contrast in every 3x3 non-overlapping patch and is the highest grey value in the current patch, is the lowest grey value in the current patch, while n is the total number of patches. Higher C values indicate better contrast – better results.

IV. Results and Discussion

The general conclusion from the observer stand point is that clarity is better and that the quality is enhanced overall, as we can see on fig. 4 and fig. 5, for low-light video seq.1 and video seq.2 while fig. 7 present the results for low-contrast video seq.3.

NR quality assessment results are presented in Table I, Table II and Table III.

The results of testing video streams for average contrast are presented in Table I, and they indicate that the measured contrast is much improved after applying dehazing on low-light video sequences, for the DCP approach. We can see that for low-contrast case (video sequence 3) contrast was 0 and it is improved with enhancement DCP algorithm on 0.1236 value.

TABLE I: AVERAGE CONTRAST PER VIDEO STREAM.

Video seq. no.	*Orig. Value*	*DCP algorithm*	*CAP algorithm*
Video seq. 1	0.132	0.211	0.1023
Video seq. 2	0.0832	0.1524	0.0805
Video seq. 3	0	0.1236	0.005

TABLE II:OBJECTIVE ASSESSMENT FOR VIDEO SEQUENCE 1.

Video seq. no.1	*e*	*r*	*δ*	*FADE*	*CNC*
DCP	0.5237	5.181	5.5%	0.1552	1.3125
CAP	-0.3993	1.61	27%	0.2580	2.7904

TABLE III: OBJECTIVE ASSESSMENT FOR VIDEO SEQUENCE 2.

Video seq. no.2	*e*	*r*	*δ*	*FADE*	*CNC*
DCP	0.8094	4.340	6.5%	0.1068	1.3725
CAP	-0.3722	1.129	32%	0.2179	2.7964

TABLE IV: OBJECTIVE ASSESSMENT FOR VIDEO SEQUENCE 3.

Video seq. no.3	*e*	*r*	*δ*	*FADE*	*CNC*
	1.0907	5.723	0.21%	0.2024	1.352

Values for e and r for video seq. 1, video seq. 2 and video seq. 3, are in range of the expected values [12], [13], and [14] while high value of r indicates that the ratio of gradient between visible edges before and after enhancement is high, which is good. Value of δ is giving the ratio of saturated pixels (black and white) only in enhanced image, and values for video seq. 1 and video seq.2 is higher than in the case of video seq. 3, but the results are comparable with literature [12], [13],[16]. According to the metric *Visible Edge Based Method* [12], best improvement is in the video seq. 3, while values for CNC metric [15] give opposite impression, in the case of DCP algorithm. According to [17] FADE, can provide good results on measuring the fog residue of dehazed image. Value of FADE is much higher for the CAP then DCP algorithm, which means that DCP leaves less "fog" then CAP. It influences on a higher contrast and better visibility. Lower value of FADE denotes better contrast enhancement, while a higher value of other metrics denote better haze removal for DCP approach.

Results for FADE are comparable with the results obtained in [14] for low-light and low-contrast case.

The higher the value of CNC, the better enhancement is, and the results that we obtained here are comparable with the results of other dehazing algorithms [12] [13]. CNC index is sometimes inconsistent, and as it is based only on dehazed image and does not take original image in consideration.

Results are indicating that overall DCP performances are better than CAP algorithm according to the objective performance measures.

V. Conclusion

In this work we presented a comparison of dehazing algorithms that can be used for low-light and low-contrast image enhancement, based on the fact that low-light images could be considered similar with hazy images. We modified dehazing video algorithms accordingly, and applied it on the inverted video, and then inverted the dehazed video again to produce the output enhanced low-lighting video. It can also be seen that additional enhancement techniques – contrast adjustment, median filtering and unsharp-mask bring visible enhancement of the images with an insignificant processing cost.

Results of dehazing algorithms are measured using objective no reference quality metrics. Both the visual and statistical results presented in this paper shows that the tested dehazing methods can be successfully used for offline video processing applications, in the frame-by-frame processing manner. Dehazing methods for real-time video processing that uses machine learning will be direction of our future research activities.

References

[1] Vlatacom Institute, "Vlatacom Institute Border Protection - Land," [Online]. Available: https://www.vlatacominstitute.com/border-protection-land. [Accessed 8 8 2018].

[2] B. Stojanović, V. Lukić, S. Milićević, S. Stanković, "Maritime surveillance image enhancement: a comparison and improvement of dehazing techniques," *in Proc. of 4th International Conference on Electrical, Electronics and Computing Engineering*, IcETRAN 2017, Kladovo, Serbia.

[3] B. Stojanović, S. Milićević and S. Stanković, "Improved dehazing techniques for maritime surveillance image enhancement," Serbian Journal of Electrical Engineering, vol. 15, no. 1, 2018

[4] B. Stojanović, S. Puzović, N. Vlahović, R. Petrović, S. Stanković, "Real-Time Multi-Sensor Infrared Imagery Enhancement," 14th Symposium on Neural Networks and Applications (NEUREL), Belgrade, Serbia, November 2018.

[5] K. He, J. Sun and X. Tang: Single Image Haze Removal Using Dark Channel Prior, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 33, No. 12, 2011, pp. 2341 − 2353.

[6] Q. Zhu, J. Mai and L. Shao, "A Fast Single Image Haze Removal Algorithm Using Color Attenuation Prior," *IEEE Transactions on Image Processing*, Vol. 24, No. 11, 2015, pp. 3522 − 3533.

[7] B. Cai, X. Xu, K. Jia, C. Qing, D. Tao, "Dehazenet: An End-to-End System for Single Image Haze Removal," *IEEE Transactions on Image Processing*, vol. 25, No. 11, 2016, pp. 5187 −5198.

[8] X. Dong, G. Wang, Y. Pang, W. Li, J. Wen, W. Meng, Y. Lu," Fast efficient algorithm for enhancement for low lightning video, " IEEE International Conference on Multimedia and Expo, Barcelona, 2011.

[9] S. Kim and J. Allebach, "Optimal unsharp mask for image sharpening and noise removal, " Journal of Electronic Imaging, vol. 14, no. 2, p. 023005, 2005.

[10] W. Wang, X. Yuan, "Recent advances in image dehazing," *IEEE/CAA Journal of Automatica Sinica,* vol.4, no.3, pp. 410-436, 2017.

[11] X. Fu, Q. Lin, W. Guo, X. Ding and Y. Huang, "Single image de-haze under non-uniform illumination using bright channel prior," *Journal of Theoretical and Applied Information Technology*, vol. 48, no. 3, pp. 1843-1848, 2013.

[12] N. Hauti`ere, J. P. Tarel, D. Aubert, "Blind contrast enhancement assessment by gradient rationing at visible edges," *Image Analysis and Stereology Journal* 27(2) pp. 87−95, 2008.

[13] K. Huang, Q. Wang, Z. Wu, "Natural color image enhancement and evaluation algorithm based on human visual system," *Elsevier Journal Computer Vision and Image Understanding*, 13 (2006), pp. 52-63.

[14] F. Guo and Z. Cai, "Objective Assessment Method for the Clearness Effect of Image Defogging Algorithm," *Acta Automatica Sinica*. 38(9) pp. 1410-1419, 2012.

[15] L. K. Choi, J. You and A.C. Bovik, "Referenceless Prediction of Perceptual Fog Density and Perceptual Image Defogging," *IEEE Transactions on Image Processing* 24(11) pp. 3888-3901, 2011.

[16] F. Guo, J. Tang, Z. Cai, "An objective assessment method for image defogging effects," *Int. J. Autonomous and Adaptive Communications Systems, Vol. 8*, Nos. 2/3, 2015.