An effective foggy image acquisition algorithm in multimedia big data era

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Abstract: Outdoor images are often degraded by fog weather conditions in the era of multimedia big data, which affect computer vision applications severely. In this paper, an effective fog image acquisition algorithm based on big data analysis is proposed in the big data environment, and single image defogging algorithm based on histogram equalisation and dark channel prior methods is proposed. The transmission and air light of the fog image need to be estimated by the dark channel prior theory methods, and then clear images can be received after defogging and keep the original colour. The experimental results show that the image by fog removal dark channel prior method can get clear images and keep the original colour, the treatment effect is better than that of the histogram equalisation method.

Keywords: multimedia big data; foggy image; effective foggy image acquisition algorithm; image restoration.


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1 Introduction

In the era of multimedia big data, fog image acquisition algorithm has played in important role in multimedia application. Many outdoor images were affected by bad weather conditions in big data era. The collected images are degraded, colour saturation and contrast are reduced which have a great effect on the outdoor vision detection system. The image and the video data are very big. The big data analytics considers image data to uncover the hidden patterns, unknown correlation, and so on. In a way, the aim of image analysis is to get the useful information from the big image data. In the foggy condition, the light beam of the object will be affected by the atmosphere because of scatter and refract phenomena, then the light received by the imaging device cannot reflect the light intensity of the object and the real information, so the fog degraded image restoration technology has important theoretical significance and wide application prospect. The research of fog image restoration is relatively difficult, the main reason is as follows:

1 Lack of prior information, atmospheric particles, conditions and scene distribution which lead to the degradation of fog image quality.

2 Degradation model is not accurate enough.

3 Complexity of the target scene will increase the difficulty of extracting the effective information of the fog image, thus increase the difficulty of image restoration.

4 colour of the degraded image is difficult to recover.

In Tripathi and Mukhopadhyay (2012) reported algorithms for the removal of fog were reviewed. It referred that estimation of depth information is under constraint problem if single image is available. Removal of fog requires assumptions or prior information. In Fattal (2008), the albedo of the scene and the medium transmission are estimated under the assumption that the transmission and the surface shading are locally uncorrelated. The method is physically sound and can be achieved impressive results.
But it cannot handle heavily hazy images well and may fail in the cases where the assumption is broken. In Raul and Juan (2015), a recovering method is proposed for images captured for several adverse weather conditions based on the RGB response ratio constancy under illuminant changes. It improves the visibility, contrast, and colour in degraded images with low computational times. In Deepak and Bhupendra (2016), a new I2-normal-based prior to generate a dark channel is proposed in order to remove the haze from a single-input image. The dark channel generated using this new prior is more robust and free from the block-effect. A statistical technique for air light estimation of a given image is also proposed. In Ling and Li (2016), the paper proposed an efficient single dehazing algorithm via adaptive transmission compensation based on human visual system (HVS), the approach is presented to suppress the halo artefacts and noise via just-noticeable distortion of HVS. Tian and Duan (2016) proposed a feasible, simple, and effective spectral power distributions (SPD) calculating method based on analysing the transmittance functions of absorption and scattering along the path of solar radiation through the atmosphere in the visible spectrum.

In this paper, a literature survey about various existing fog remove algorithm and analysis their advantages and disadvantages are given. Fog image acquisition and processing system is designed in the environment of LabVIEW, single image defogging algorithm including histogram equalisation and dark channel prior (DCP) methods are used. Performance analysis of the two algorithms and an evaluation of their advantage and disadvantages are given.

The rest of this paper is organised as follows. Section 2 discusses the image degradation theory. The histogram equalisation and DCP are discussed in Sections 3 and 4. Section 5 shows the image restoration system based on LabVIEW and results, and Section 6 concludes the paper.

## 2 Fog image degradation theory

Under certain conditions of weather, when pollutants and smoke are not able to disperse, they cling together to form a hazy cloud at a low level. Fog evolves when some of the haze particles grow by condensation into water droplets. Haze particles grow by condensation into water droplets. A hazy cloud at a low level. Fog evolves when some of the weather, water droplets float in the air. These droplets are very small in size. Thus, in fog, image intensity produced at a pixel is the combined effect of the large numbers of water droplets within the pixels solid angle (Garg and Nayar, 2007). The interaction between incident light and atmosphere changes the light path, leading to the incident light no longer travelling in a straight line. It will be weakened with the increase of the target scene depth, so that the fog image is not clear and has a low contrast. The main reason is that there are several problems (Zhang and Zheng, 2005):

1. The non-uniform distribution of fog has a certain influence on the camera system.
2. In the fog days, the brightness of the sky decreased in the fog days.
3. In the case of fog, multiple scattering phenomena will occur.

In addition, the Rayleigh scattering model said that the atmospheric scattering coefficient is related to wavelength of the light, different colours of the light give rise to the different wavelength, so different colours of light have different scattering effects. As a foggy day, the colour of the collected image will be deviated.

In Tripathi and Mukhopadhyay (2012), the contrast and colour of the images under fog weather conditions are drastically degraded. The degradation level increase with distance from camera to the object. Initial works in fog removal are based on the contrast enhancement without any knowledge of the fog model. Thus, the algorithms can be categorises in enhancement-based and restoration-based approaches. The most commonly used methods in enhancement-based approaches are histogram equalisation and its variants. The restoration-based approaches use physics-based models to estimate the pattern of image degradation and then recover the scene contrast.

The degraded image of the fog is caused by the attenuation of the incident light and that of air, so the fog image degradation model can be described as:

\[ I(x, \lambda) = E_0 = (\lambda)e^{-\beta(\lambda)d} + E_\infty(\lambda)(1-e^{-\beta(\lambda)d}) \]  

(1)

where \(d\) is the scene depth.

In the practical process, the influence of the wavelength of the optical wave is neglected, so the image degradation model can be simplified as:

\[ I(x) = t(x)J(x) + (1-t(x))A \]  

(2)

In which \(t(x)\) and \(J(x)\) express as the original image and the processed image, respectively. \(t(x)\) is the medium transmission of atmosphere, \(A\) is the global atmospheric light. The goal of fog removal is to recover \(J, A,\) and \(t\) from \(I\).

## 3 Algorithm of histogram equalisation

The basic principle of histogram equalisation (Gonzalez and Woods, 2010) is to change pixel gray value of original image, so that the final image is relatively clear after improving the quality of the image. Consider for a moment continuous intensity values and let the variable \(r\) denote the gray value of an image to be processed. As usual, \(r\) is in the range \([0, 1]\), with \(r = 0\) representing black and \(r = 1\) representing white. The probability density function is transformed by the formula:

\[ s = T(r) \quad (0 \leq r \leq 1) \]  

(3)

In this process, the optical wave is neglected, so the image degradation model can be simplified as:

\[ I(x) = E_0 + E_\infty(1-e^{-\beta(\lambda)d}) \]  

(1)

In which \(E_0\) and \(E_\infty\) express as the original image and the processed image, respectively. \(E_\infty\) is the medium transmission of atmosphere, \(E_0\) is the global atmospheric light. The goal of fog removal is to recover \(I\), so that the final image is relatively clear after improving the quality of the image.
According to the uniform probability distribution function, the formula (3) should be satisfied the following two conditions:

1. \( T(r) \) (0 ≤ \( r \) ≤ 1) is the monotonically increasing function.

2. 0 ≤ \( s = T(r) \) ≤ 1 for 0 ≤ \( r \) ≤ 1. The first condition is that the whole gray level is still in the order of black to white.

The second condition is to guarantee the consistency of the dynamic range of gray value before and after the transformation.

Assumed that the transform function is as follows, \( T(r) \) is the cumulative distribution function of \( r \):

\[
s = T(r) = \int_0^r p_r(w)dw
\]

in the case of satisfying the above two conditions, the distributions of \( r \) can be converted into the uniform distribution of \( s \) by cumulative distribution function. When the gray level is discrete value, probability value can be substituted frequency, \( P_r(r_k) \) is the probability of the \( k \) class gray value, \( n_k \) expressed the number of the \( k \) class gray value, one is the total number of gray level, \( n \) is the total number of pixels:

\[
P_r(r_k) = \frac{n_k}{n} \quad 0 \leq r_k \leq 1 \quad k = 0, 1, 2, ..., l - 1
\]

From the above formula, the cumulative distribution function is obtained:

\[
s_k = T(r_k) = \sum_{j=0}^{r_k} \frac{n_j}{n} = \sum_{j=0}^{r_k} p_r(r_j) \quad 0 \leq r_j \leq 1
\]

Histogram equalisation can be achieved using histeq function in MATLAB. Each colour channel (R, G, B) is processed and then fused into a colour image. In the treatment effect, this method can make the original distribution of the histogram becomes uniform after the treatment. Each gray level uniformly distributes pixel image, and processed image also become clear and get a better visual effect.

4 DCP algorithm

4.1 Dark channel theory

Owing to its effectiveness in defogging, the majority of recent defogging techniques have adopted the DCP method (Lee and Yun, 2016). The DCP is a statistical rule (He and Sun, 2011; Shao and Chang, 2015), in which He ect. He and Sun (2011) go through a large number of images. Some pixels (called dark pixels) often have very low intensity in at least one colour (RGB) channel in local region. That is to say, in foggy images, the intensity of these dark pixels in that channel is mainly contributed by the air light. These dark pixels can directly provide an accurate estimation of the fog transmission. For an arbitrary image \( J \), its dark channel \( J_{\text{dark}} \) is given by:

\[
J_{\text{dark}}(x) = \min_{y \in \Omega(x)} \left( \min_{c \in \{R,G,B\}} \frac{J_c(y)}{A^c} \right)
\]

where \( J \) is a colour channel of \( J \) and \( \Omega(x) \) is a local patch centred at \( x \). \( y \) is the corresponding pixel in the region. Using the concept of a dark channel, if \( J \) is an outdoor fog-free image, except for sky region, the intensity of dark channel is low and tends to zero.

This paper takes the local small blocks of 15 * 15 pixels for image restoration processing. Dark channel of foggy image is significantly brighter than the former. In the visual effect, it is equivalent to the thickness of fog.

4.2 Transmittance estimation

From the former analysis, we can conclude that removing the fog needing the transmittance \( t \) and the global atmospheric light \( A \). When estimating the transmittance, it is assumed that the air light is given firstly, and then it is assumed that the transmittance is the same in each local small piece. Based on the formula (2) to take minimum operation of R, G, B three colour channel. Firstly the fog imaging equation (2) is normalised by \( A \), then calculate the dark channel on both sides and put the minimum operators on both sides:

\[
\min_{c} \min_{y \in \Omega(x)} \left( \frac{I_c(y)}{A^c} \right) = \tilde{I}(x) \min_{c} \min_{y \in \Omega(x)} \left( \frac{J_c(y)}{A^c} \right) + \left( 1 - t(\tilde{x}) \right)
\]

where \( J_c \) is a colour channel of \( J \) and \( \Omega(x) \) is a local patch at \( x \). Equation (8) can be expressed with the equation (9) by fog image transmission:

\[
\tilde{I}(x) = 1 - \min_{c} \min_{y \in \Omega(x)} \left( \frac{I_c(y)}{A^c} \right)
\]

By dark channel theory, the dark colour of the no fog image is close to 0, and \( A^c \) is always greater than 0, so we can get the equation:

\[
\min_{c} \min_{y \in \Omega(x)} \left( \frac{J_c(y)}{A^c} \right) = 0
\]

Equation (8) can be expressed with the equation (9) by fog image transmission:

\[
\tilde{I}(x) = 1 - \min_{c} \min_{y \in \Omega(x)} \left( \frac{I_c(y)}{A^c} \right)
\]

In general, the fog image colour in the sky region is close to the air light. The above formula’s second item tends to 1. While the transmittance in the sky region is close to 0, then the formula (10) can meanwhile deal with the image including sky and non sky area. When an object is far away, that is to say, the image has a large scene depth, it seems to have a layer of fog on it. When the image is recovered, it will be not natural after removing the fog completely. So adding a parameter ‘w’, then the transmittance:

\[
\tilde{I}(x) = 1 - w \min_{c} \min_{y \in \Omega(x)} \left( \frac{I_c(y)}{A^c} \right)
\]

Taking ‘w = 0.95’ in this paper.
Secondly, the soft matting algorithm is used to improve the transmittance distribution function. \( t(x) \) refers to the transmittance map after the processing, \( \tilde{t}(x) \) will be written in vector form \( t \) and \( \tilde{t} \) respectively, and to minimise the cost function (Levin and Lischinski, 2006): 

\[
E(t) = \tilde{t}^T L t + \lambda (t - \tilde{t})^T (t - \tilde{t}) 
\]

(12)

in which \( L \) is the matting Laplace matrix, \( \lambda \) is the corrected parameter, elements \((I, J)\) and \( L \) matrix are defined as follows:

\[
\sum_{k,\delta_{i,j}>0} \delta_{i,j} \left[ 1 + \frac{1}{|\delta_{i,j}|} \left( I_i - u_k \right)^T \left( \sum_k \frac{\epsilon}{|\delta_{i,j}|} U_j \right)^{-1} \right] 
\]

(13)

where \( I_i \) and \( I_j \) are the colours of foggy day image \( I \) at \( i, j \); \( \mu_k \) is the mean value; \( \sum_i \) indicates the variance; \( \delta_{i,j} \) is the Kronecker delta, \( \epsilon \) is a correction parameter, \( U_j \) is a \( 3 \times 3 \) unit matrix; \( |\delta_{i,j}| \) is the number of local small pixels.

The optimal \( t \) can be obtained by solving the following sparse linear systems:

\[
(L + \lambda U)\mu = \lambda \tilde{t} 
\]

(14)

where \( U \) is identity matrix of the same size as \( L \). In this method, taking \( \lambda = 0.0004 \), then \( t \) and \( \tilde{t} \) is relevant.

In the process of image restoration, the block effect of the processed image can be effectively eliminated and the edge details can be clearer.

4.3 Air light estimation

The dark channel of foggy image can be regarded as the concentration of fog. At first, the maximum brightness of 0.1 percent pixels in the dark channel is taken, and then the maximum brightness value in the fog image region corresponding to these pixels is used as the estimated value of the air light \( A \). But when tends to 0, the restored image often contains noise. For this, taking the lower limit \( t(x) \) as \( t_o \), and making it equal to 0.1. Finally we can get the equation:

\[
J(x) = \frac{I(x) - A}{\max(t(x), t_o)} + A 
\]

(15)

5 Restoration system based on LabVIEW and results

LabVIEW is a development environment designed specifically to accelerate the productivity of engineers and scientists. With a graphical programming syntax that makes it simple to visualise, create, and code engineering system. LabVIEW can help reducing test times, deliver business insights based on collected data, and translate ideas into reality. It is designed to interoperate with other software, such as MATLAB. Image acquisition and recovery system designed by LabVIEW mainly includes front panel, image acquisition module and image processing module. Image acquisition module is achieved with the IMAQ USB function. First, the image task can be created by control icon ‘IMAQ create’, then the USB driven function calls USB camera. The video and image can be obtained and displayed in the front panel. The image processing module is the core of the system; it is mainly used for processing with histogram equalisation and dark channel methods. The image processing function is accomplished through the image processing toolbox of MATLAB, then the MATLAB script will be called by the LabVIEW to achieve mixed programming (Xu and Yu, 2005), then we can get recovered image. The image restoration results can be display and saved by the LabVIEW program.

Before image acquisition, the VAS and VDM toolbox must also be installed, and the selection of sub VI will be appeared in the motion and visual toolbox, so that the program can be programmed, acquired and saved smoothly. Here, The JPEG format is used to save the captured image.

The realisation of image processing in the module is called by MATLAB image processing toolbox in the LabVIEW environment. The image is loaded by the sub VI (read JPG file), the original image will be displayed on the front panel of LabVIEW through the VI (draw flattened pixmap) and display control icon, then converting the path to be the string of characters which is connected to the input parameter of MATLAB Script, and converting the category of input to be ‘string’ in order to call the m.file to display the image. Secondly, importing the debugging m.file that is used to restore the image to the node of ‘MATLAB Scrip’. Finally, the character is converted to the path of output and image will be displayed on the front panel which including the image in processing and the final image after restoration.

The colour image histogram equalisation and the DCP theory are separately used to restore the foggy image. The following gives three foggy image and their recovery results from fog removing.

5.1 Histogram equalisation results

When the weather is in the mist condition, Figure 1 and Figure 3 are the original image; Figures 2 and 4 are the processed image by histogram equalisation. Through the experimental result, it can be observed that when the image histogram is uniform case, processed result is not obvious. As shown in Figure 2, contrast of colour is too enhanced; the recovered image appears to be unnatural. When the image contains larger noise, the processed image tone will be changed. There is a serious distorting phenomenon, and some of the information in the image is lost, and it cannot achieve the desired results.
In the thicker fog conditions, Figure 5 is the original image, and Figure 6 is a histogram equalisation graph.

The results show that this method can not only achieve a good visual effect when it deals with a larger image, but also appears a significant block phenomenon.

5.2 DCP results

In the mist fog conditions, Figure 7 is the dark channel image of the fog image (Figure 1) in the restoration process. Figure 8 is the distribution image of the transmission before optimisation and Figure 9 is the distribution image of the transmission after optimisation. Figures 10 and 12 are the original image. Figures 11 and 13 are the restored image.
We can see that the restored image is better than the original one. Although it still not very clear, it do not appear particularly excessive contrast enhancement phenomena, the visual effect looks more natural.

When the fog concentration is larger, Figure 14 is the original and Figure 15 is restored image. This method is much better than the effect of histogram equalisation, and there is no block phenomenon.

By comparing these images of before and after restoration, the restored image is obvious to remove a layer of fog, and looks clearer than the original. Compared with the histogram equalisation method, the visual effect by DCP is clearer and acceptable.
6 Conclusions

In this paper, single image defogging algorithm based on histogram equalisation and DCP methods is proposed, and an effective fog image acquisition algorithm system is designed. The map which distribution is too concentrated will be uniformed by histogram equalisation to remove the effect of fogging. For small foggy images, the contrast ratio of image can be got increased adopting histogram equalisation method, but there will be too much contrast enhancement phenomenon. The transmission and air light of the fog image need to be estimated by the DCP theory methods, then clear images can be received after defogging and keep the original colour, the treatment effect is better than that of the histogram equalisation method.

Acknowledgements

This work was supported by Henan Province Science and Technology Project under Grant No. 172102210370 and Henan Province Department of Education Project under Grant No. 16B460007. The authors would like to thank the anonymous reviewers and the editor for the very instructive suggestions that led to the much improved quality of this paper.

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