Image Restoration using Wigner Distribution for Night Vision System

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Abstract—Night vision systems have become an important research area in recent years. Due to variations in weather conditions such as snow, fog, and rain, night images captured by camera may contain high level of noise. These conditions, in real life situations, may vary from no noise to extreme amount of noise corrupting images. Thus, ideal image restoration systems at night must consider various levels of noise and should have a technique to deal with wide range of noisy situations.

In this paper, we have presented a new method that works well with different signal to noise ratios ranging from -1.58 dB to 20 dB. For moderate noise, Wigner distribution based algorithm gives good results, whereas for extreme amount of noise 2nd order Wigner distribution is used. The performance of our restoration technique is evaluated using MSE criteria. The results show that our method is capable of dealing with the wide range of Gaussian noise and gives consistent performance throughout.

Keywords- Night vision, Image Restoration, Wigner distribution

I. INTRODUCTION

Night Vision systems are becoming extremely useful and critical, as accident rate during nighttime is higher than that during daytime. During night, drivers face a problem of low contrast vision and noisy (due to fogs, snow, and rain) view, both leads to unclear interpretation of the scene. This becomes even severe for elderly people. Many researchers have been working in the areas of night image enhancement, super-resolution image, multi-spectral imaging, night vision goggles and image fusion to combat night vision issues. In image enhancement, histogram equalization method is commonly used. However, histogram equalization considers global image information to process the image resulting in improper enhancement at object or local level [1]. In super-resolution or multi-spectral techniques, one more imaging modality is required. This increases overheads on the hardware. Additionally, speed is a major concern in such applications and thus it cannot be compromised. Night vision goggles suffer from disorientation and offer a small field of view to the user [2].

We present image restoration methodology to for use in night vision systems. The technique helps overcome poor image quality due to fog, snow, and rain. The algorithm processes noisy images and gives better visibility to driver to identify obstacles or pedestrians. This restoration technique is based on Wigner distribution. Night vision system involves the capturing image with CCD camera and enhancing the image with proposed scheme. Restored image can be displayed to the driver or with further image processing; he can be alerted with the presence of obstacle.

This technique involves three methods for noise removal. In case of very low noise the image restoration can be avoided. For medium noise level, 1st order Wigner distribution is used. In high level of noisy images, 2nd order Wigner distribution is employed. The Wigner distribution has a good capability of removing noise [3]. This capability can be further increased by applying 2nd order Wigner distribution in the presence of large noise. It is assumed that quantitative analysis of noise present in the image is computed first. Depending on the level of noise, one of the three method of noise removal is applied.

Section II discusses the theory of Wigner distribution and its associated parameters. How Wigner distribution can be used for the images, is explained in subsection. Section III presents the methodology involved in our noise removal algorithm. Experimental results are reported in section IV in order to observe the performance of our image restoration technique to be used in night vision system. Performance metric, MSE, is calculated to give quantified robustness of the algorithm for different situations. Finally, the paper is concluded with concluding remarks, comments and claim of robustness that can be achieved by our algorithm. Future work is also briefly discussed in conclusion.
II. WIGNER DISTRIBUTION

Wigner distribution is a generalized time–frequency representation. The characteristic of the Wigner distribution, to be a function of both time and frequency, is remarkable. The Fourier transform, on the other hand, is strictly a function of frequency [4]. Wigner [5], in 1932, proposed this function for the study of quantum mechanics. Ville [6] proposed it again in 1948. However, researchers did not pay much attention to the method until the 1980s, when researchers in the speech processing area, extensively used this concept in 1980s.

The Wigner distribution of two signals \( f(t) \) and \( g(t) \), is defined as
\[
WD_{f,g}(t, \omega) = \int_{-\infty}^{\infty} e^{-j\omega k} f(t + k/2) g^*(t - k/2) dk
\]
(1)

Where \( \omega \) is the frequency, \( t \) is time and \( g^* \) is the complex conjugate of the function \( g(t) \). The auto-Wigner distribution of signal \( f(t) \) is given by
\[
WD_f(t, \omega) = \int_{-\infty}^{\infty} e^{-j\omega k} f(t + k/2) f^*(t - k/2) dk
\]
(2)

The auto-Wigner distribution for real function \( f(t) \) is given by
\[
WD_f(t, \omega) = \int_{-\infty}^{\infty} e^{-j\omega k} f(t + k/2) f(t - k/2) dk
\]
(3)

In discrete domain the Wigner function is defined as
\[
WD_{f,g}(t, \omega) = 2 \sum_{k=-\infty}^{\infty} e^{-j2\omega k} f(t + k) g^*(t - k)
\]
(4)

The auto-Wigner distribution is defined as
\[
WD_f(t, \omega) = 2 \sum_{k=-\infty}^{\infty} e^{-j2\omega k} f(t + k) f^*(t - k)
\]
(5)

If the function is real then auto-Wigner distribution is defined as
\[
WD_f(t, \omega) = 2 \sum_{k=-\infty}^{\infty} e^{-2\omega k} f(t + k) f(t - k)
\]
(6)

The equation (6) is useful in the development of the Wigner distribution for the image processing:

\[Pseudo\ Wigner\ distribution:\]

The inclusion of window in Wigner distribution definition gives Pseudo Wigner distribution in order to reduce the computations. For a real and discrete function \( f(t) \) with a window \( w \) of duration \( 2d + 1 \), Pseudo Wigner distribution can be given as
\[
PWD_f(t, \omega) = 2 \sum_{k=-d}^{d} \cos(2\omega k) w(k) f(t + k) w(-k) f(t - k)
\]
(7)

\[Wigner\ Distribution\ for\ Image\ Processing:\]

To use the Wigner distribution function for image processing, it is extend to two-dimensional space. Such an extension results in a four–dimensional Wigner distribution function. The function has two space-domain variables \( x \) and \( y \), and two frequency–domain variables \( u \) and \( v \). The extension to 2D space is then
\[
WD(x, y, u, v) = \frac{4}{MN} \sum_{l=-N/2}^{N/2} \sum_{m=-M/2}^{M/2} \cos(\theta) f(x + k, y + l) * f(x - k, y - l)
\]
(8)

Where image size is \( M \times N \), window size is \( M' \times N' \), \( f \) is the gray-scale function and \( \theta = 4\pi[uk/M + vl/N] \). In pseudo-Wigner distribution, the main Wigner kernel is multiplied by another kernel like exponential, \( e^{-\|k\|\|l\|} \). Then equation (8) becomes
\[
WD(x, y, u, v) = \frac{4}{MN} \sum_{l=-N/2}^{N/2} \sum_{m=-M/2}^{M/2} e^{-\|k\|\|l\|} \cos(\theta) * f(x + k, y + l) * f(x - k, y - l)
\]
(9)
The main objective behind using this kernel is the candidate pixel \((x, y)\) where WD is being calculated should have maximum influence on the calculations, whereas as one goes away from the candidate pixel, its influence should rapidly decay out. In order to enhance the image range, equation (9) can be scaled by gain factor, \(\alpha\).

Then the equation becomes

\[
WD(x, y, u, v) = \frac{4\alpha}{MN} \sum_{l=-N/2}^{N/2} \sum_{k=-M/2}^{M/2} e^{-|x-k|^2/4l^2} \cos(\theta) 
\]

\[
\times f(x+k, y+l) * f(x-k, y-l)
\]  \(10\)

Refer to Vaidya [9] for in depth study of Wigner Distribution for image processing.

Equation (10) gives the 1st order Wigner distribution. The 2nd order distribution is obtained by applying 1st order Wigner distribution on the output of 1st order Wigner distribution of the image.

### III. METHODOLOGY

As mentioned before, it is assumed that the qualitative analysis of noise present in image is available. Thus, captured image will be categorized in one of the three classes. Low/no Noise image, medium noise image and high noise image. Depending on the class, the image is treated differently in our image restoration technique to be used in night vision system. For low noise image no image restoration is applied. For medium noise level, 1st order Wigner distribution is used. In high level of noisy image, 2nd order Wigner distribution is employed. The Wigner distribution has a good capability of removing noise. This capability can be further increased by applying 2nd order Wigner distribution in the presence of large noise. We use kernel of Wigner distribution for achieving good quality of contrast in image and reduction of noise. For all our results, we have used equation (10), with \(\theta = 0\) to have a DC filtering over an image so that image gets smoothened. Window size used is 3x3. The value of 1000 is used for the scale factor \(\alpha\).

The exponential kernel used here is defined by

\[
ker_{nel} = e^{-2||k||^2/4l^2}
\]  \(11\)

One can see from the results that the product term, in equation (10) is responsible for reducing high frequency noise component and enhancing low contrast part of the image. After calculation of Wigner distribution, it is scaled by some factor, \(\alpha\) so that range of Wigner coefficients is extended.

### IV. EXPERIMENTAL RESULTS

The algorithm was developed using Clmg Library [8]. Image used here is of size 137 x 103 and has car as an object. However to simulate different situations, this image was used with additive Gaussian noise giving different SNR in the input image. First order and second order Wigner distribution are applied on these images. The noise added to the signal was of 0 %, 5%, 10%, 20%, 30%, 50%, 80%, 100%, and 120% of the peak to peak signal strength of original image. Thus, experiment repeated for SNR of very large (no noise), 26 dB, 20dB, 14dB, 10dB, 6dB, 2dB, 0dB and -1.58 dB to evaluate the robustness of the Wigner distribution based algorithm. The quantitative analysis is done with the help of MSE. To do subjective evaluation of our methodology, readers are referred to figure 1-9. Images shown in figure 1-9 have witnessed the effectiveness of our image restoration algorithm. The result of our algorithm in terms of MSE and percentage improvement is shown in table 1.

<table>
<thead>
<tr>
<th>%noise</th>
<th>SNR in dB</th>
<th>MSE of noisy image</th>
<th>MSE of restored image obtained by our algorithm</th>
<th>% Improvement</th>
</tr>
</thead>
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<tr>
<td>0</td>
<td>No-noise</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>26</td>
<td>0.159</td>
<td>0.159</td>
<td>-17.00</td>
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<td>20</td>
<td>0.272</td>
<td>0.179</td>
<td>34.12</td>
</tr>
<tr>
<td>20</td>
<td>14</td>
<td>0.475</td>
<td>0.173</td>
<td>63.51</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>0.652</td>
<td>0.212</td>
<td>67.47</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
<td>0.83</td>
<td>0.2171</td>
<td>73.83</td>
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<tr>
<td>80</td>
<td>2</td>
<td>1.09</td>
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</tr>
<tr>
<td>100</td>
<td>0</td>
<td>1.12</td>
<td>0.225</td>
<td>79.92</td>
</tr>
<tr>
<td>120</td>
<td>-1.58</td>
<td>0.911</td>
<td>0.308</td>
<td>66.16</td>
</tr>
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</table>

TABLE 1. FOR DIFFERENT SNR, THE RESULT OF OUR ALGORITHM WITH MSE AND PERCENTAGE IMPROVEMENT
The MSE is calculated for 1\textsuperscript{st} and 2\textsuperscript{nd} order Wigner distribution of noisy image with respect to that of noiseless image. MSE for different SNR are recorded in the table 2. The shaded area of table gives the result obtained by our algorithm for different noisy conditions. Observing improvement factor for different SNR images, performance of the Wigner based restoration technique to be used in night vision algorithm can be accepted with high confidence.

V. CONCLUSION

The Night vision systems primarily suffer from factors as low-resolution image, low contrast and noise due to fog, snow, or rain. We have presented a new technique to provide effective image restoration by reducing the effect of noise. With such restoration, object or obstacle presented in the scene can be made clear to assist driver. In order to deal with different levels of noise effectively, this technique divides noise in three methods namely low, medium and high. Noise removal can be skipped for low, 1\textsuperscript{st} order Wigner distribution is used for medium noise and 2\textsuperscript{nd} order Wigner distribution is applied for high level of noise. The performance of our algorithm is evaluated with MSE criteria. The result shows the effectiveness of our algorithm even in image with SNR of -1.58 dB.

The future work includes the image restoration for very low noise so that edges in the image can be preserved.

Also, qualitative analysis of noise level in captured image will be on higher priority.

REFERENCES


<table>
<thead>
<tr>
<th>%noise</th>
<th>SNR in dB</th>
<th>MSE of noisy image</th>
<th>MSE of 1\textsuperscript{st} order WD</th>
<th>MSE of 2\textsuperscript{nd} order WD</th>
<th>% improvement in 1\textsuperscript{st} order WD</th>
<th>% improvement in 2\textsuperscript{nd} order WD</th>
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<td></td>
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</tr>
<tr>
<td>120</td>
<td>-1.58</td>
<td>0.911</td>
<td>0.653</td>
<td>0.308</td>
<td>28.31</td>
<td>66.16</td>
</tr>
</tbody>
</table>
Figure 1 - Image with no noise, 1st order Wigner Distribution and 2nd order Wigner Distribution

Figure 2 - Image with SNR 20 dB, 1st order Wigner Distribution and 2nd order Wigner Distribution

Figure 3 - Image with SNR 10 dB, 1st order Wigner Distribution and 2nd order Wigner Distribution

Figure 4 - Image with SNR 0 dB, 1st order Wigner Distribution and 2nd order Wigner Distribution

Figure 5 - Image with SNR -1.58 dB, 1st order Wigner Distribution and 2nd order Wigner Distribution