Enhancement Of Atmospheric Turbulence Distorted Images Using Wavelet Packet Transform

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Abstract: Image enhancement is the process of sharpening image feature so that it is more suitable for some specific applications where the quality of the image is important for human perception. Here a multi-image enhancement technique which is based on wavelet packet transform is presented for the images distorted by atmospheric turbulence, where multiple low resolution images are processed to form a single high quality enhanced image. In wavelet packet transform both the approximation coefficients, which is the low frequency portion, and detailed coefficients, which is the high frequency portion of the previous levels, are used for processing in the next level. So without losing any part, the image can be represented with time-frequency information. This finds application in feature extraction and object recognition. Here first step is aligning the Region of Interest (ROI) from all input images using phase correlation method. Then it is combined in transform domain with the help of wavelet packet transform. Performance comparison parameters are calculated for the output image and it is compared with the parameters obtained from other techniques.

Index Terms: Atmospheric turbulence, Discrete wavelet transform, Phase correlation, Spatial frequency; Standard deviation, Wavelet packet transform.

1. INTRODUCTION:

Image enhancement sharpen of features like boundaries, edges and contrast so that it gives a better quality image compared to the original input image[2]. It has got application in the fields of satellite imaging, medical imaging [5][6] etc., and the resultant image can be used for applications such as segmentation, recognition and detection. In this image enhancement process, number of low resolution images are combined to form a single high quality enhanced image[9]. This way the amount of memory used to store multiple images can be reduced effectively. The enhanced image provides high spatial and spectral resolution. While capturing the image of a moving object from hot roads or deserts, atmospheric turbulence is a serious issue affecting the visual clarity. The various atmospheric distortions affecting the image clarity are fog, haze and atmospheric turbulence, which is caused by the temperature variation in hot roads and deserts. When the ground is heated by solar radiation, the air above the ground gets heated up, resulting in atmospheric turbulence caused by the mixing of hot and cold air. This creates horizontal layers of aerosols and changes the refractive index. As the variation in temperature between the ground and the air above it increases, the layer thickness will get reduced. This causes the layers to move upward. These variations in density of atmosphere in a line of sight with an object cause intensity fluctuations. Apparent position of an object will be altered because of the variations in the refractive index of a cell of air in front of the camera. Collectively these effects cause the individual parts of the image to move in different directions. The reduction of this distortion is difficult with a single image. So a set of images are used for the atmospheric turbulence reduction, resulting in one enhanced image.

When the multiple images of a same seen are captures, there will be a small relative motion between the scene and the camera. In such cases it is required to register or align the region of interests. In this paper, a new image enhancement technique based on wavelet packet transform is proposed for the images distorted by atmospheric turbulence effect. The advantage of using Wavelet Packet Transform is that in Wavelet Packet Transform both approximate and detailed components will be processed in each step. It helps in getting the optimal representation of the image. For higher frequency components in image, discrete wavelet transform can cause problems, as in discrete wavelet transform, only the approximation coefficients (low frequency part) of the previous level is processed in the next level. So the high frequency coefficients are not used in the further steps, and the high frequency part of the image are lost. The frequency resolution of the decomposition filter will not be good enough to take out information from the decomposed components of the image. In wavelet packet transform, both the approximation coefficients, which is the low frequency part and detail coefficients, which is the high frequency part of the previous level are used for processing in the next level. So without losing any part, the image can be represented with time-frequency information. This method can be implemented in image enhancement, for obtaining a good quality image. Also the atmospheric turbulence effect, which occurs while capturing images from hot roads or deserts, can be reduced by applying this image sequences. The rest of the paper is organized as follows. Section 2 gives the details of different papers referred. Section 3 describes the proposed enhancement technique and different performance comparison parameters that are used for checking the performance of the enhancement method. Section 4 discusses about the output and comparison of the parameters calculated using different methods. Section 5 is conclusion and future work.

2 LITERATURE REVIEW

The literature survey is mainly done on the image enhancement and various enhancement techniques. Rodrigo
Capobianco Guido [1] speaks about the basic - frequency signal analysis especially about DWT transformed signal, which has got very wide applications in signal and image processing. DWT is widely used because of its fast computation time compared to other frequency domain techniques. It clearly shows that how to interpret DWT signals very efficiently extract the time support of frequencies contained in the actual signal under analysis. N. Sangeetha and K. Anusudha [2] speaks about the image enhancement techniques that are used in situations where the images are degraded due to hay and foggy weather. Analysis was done by calculating different performance parameters. Hasan Demirel and Gholamreza Anbarjafar [3] says how DWT can be used for image enhancement in satellite images. The technique is based on the interpolation of input image and upper frequency components obtained by wavelet transform and then combine the images to get a new enhanced image. They have a stage for determining the high frequency sub band which helps in getting a sharper image. Shivani Jain and Jyoti Rani [4] says why wavelet transform is used in image enhancement techniques. They also speaks about Directional Wavelet Transform and Discrete Cosine Transform and how they can be used in different image processing applications. They show how kernel suppresses the variations which are not parallel to their direction. Directional wavelet transform is a linear transform which can be used on data where the length is power of two. Advantages of using this transform are the decomposition of signals into four dimensional space and the ability to detect singularity lines. Discrete Cosine Transform is suitable for natural images and it uses inter-pixel redundancies to provide excellent de-correlation. Kirit Khatkhar and Dinesh Kumar [5] gives a technique for biomedical image enhancement using combination of wavelets. They have used DMayer wavelets and Wavelet Coeflet for the enhancement. They have also compared the PSNR value and the BETA coefficient for different wavelets with their method. The experiment was performed on different medical images like brain, kidney, heart and liver. Roopali D Pai et al. [6] speaks about medical image enhancement using wavelets and how Haar wavelets can be used to extract the high frequency information. Haar wavelet is used to decompose the high frequency subimages. Enhancement weight coefficients in sub-images and Edge sharpening are also used in enhancement process. They also show how the algorithm is effective in preserving the edge details of the image. Nivedita Singh and M. A Ansari [7] gives an idea about the wavelet packet transform and how it is used for feature extraction. In WPT, analysis of the Detailed and the Approximate signals are separated so that it looks like a binary tree. In the tree structure the uppermost level represents the time and the lowest level represents the frequency resolution. Here the entropy of wavelets also measured so that it can choose proper wavelet filters and decomposition levels. Hasan Demirel et al. [8] gives an image enhancement technique based on DWT and Singular Value Decomposition. Here using DWT image is decomposed to subbands and then for the LL sub-band find the singular value matrix and finally reconstruct the image by taking IDWT. The proposed method was compared with the other histogram equalization techniques. S.M.Mukane et al. [9] gives an image enhancement method from multiple images. Here the multiple images are combined to give a single enhanced image. They give an idea about how wavelets are used for this enhancement technique. They have also mentioned how the combining can be done using Laplacian Pyramid and also done the performance analysis.

H. Yan and J. G. Liu [10] presented a phase correlation based sub-pixel feature matching technique and the application of phase correlation in pixel to pixel image co-registration. Phase correlation method is based on the Fourier shift property. The results show that the robust phase correlation based technique performs very well in motion flow estimation and in local and global feature matching. This technique could achieve accuracy in sub-pixel level. The main advantages of this technique are its ability to withstand illumination change, simplicity and its better performance in low correlation or featureless areas. R. Y. Tsai and T. S. Huang [11] propose a multi-frame image enhancement algorithm. This is based on the local characteristics of the input image. Here adaptive $L_0$ norm is measured and this is done by using locally adaptive bilateral total variation model as a regularization item. Data error term and gradient error term are measured using $L_1$ norm. Y. Choi et al. [12] gives techniques to compare different fusion techniques in transform domain. They have used eight separate performance quality metric to compare the results. Quality metrics are good in measuring the performance of the fusion techniques because quantitative analysis is always more precise that the qualitative analysis. Qualitative analysis depends on the personal capabilities of the individual. Min-Chun Yang and Yu-Chiang Frank Wang [13] propose a self-Learning approach for image enhancement. They have used SVR and sparse representation in their approach. Here training of low resolution and high resolution image is not required. They have used Bayes decision theory and fond the error level for the resultant method. M. Y. Gokhale and Daljeet Kaur Khanduja [14] conducted an investigation on WPT techniques. This paper tells the concept behind the Wavelet Packet Analysis (WPA) formation and the various wavelet domain sets. In terms of frequency resolution wavelet packet decomposition is better than wavelet decomposition. So the usefulness of one dimensional WPT is illustrated. WPT is a decomposition technique which represents the signal in a basis that contains both the frequency and time information. So the signal can be analyzed simultaneously in time and frequency, by using wavelet packet transform. Du-Yih Tsai and Yongbum Lee [15] proposed an image enhancement method which uses nonlinear mapping functions to project a set of DWT coefficients to new set of DWT coefficients. Nonlinear mapping functions mainly perform the edge enhancement of the image, the experiment was performed on a set of chest radiographic images. Hai-Hui Wang and Jun Wang [16] proposes a fusion method which uses GHM discrete multwavelet transform (DMWT). It offers a better and accurate analysis than wavelet multiresolution analysis. They uses a feature based rule to combine the subimages. Various frequency ranges are processed separate when the images are combined in multwavelet space. It can be used in application where the images form multisensors are need to be processed. W. Lawton [17] describes the use of wavelets in different image processing applications. They have used Daubechies wavelets to get the multiresolution representation of the images in terms of wavelet coefficients. Then multilevel processing is performed on these coefficients using different techniques. They have also discussed about the computational complexity of the techniques. K.E. Prager and P.F. Singer [18] analyses the use of wavelet transform for...
image enhancement and filtering. They have explained the concept of wavelet transform and convolution theorem. They have also used operations for sharpening and edge detection. L.J. Chipman et al.[19] describes fusion using wavelet transform. In wavelet base different frequency signals can be processed separately. High frequency and low frequency information from images can be combined for edge sharpening. They have made a system where the experiments can be conducted with different wavelets. They also speak about the image registration problems. A. Laine et al. [20] proposed a multi-scale image contrast enhancement algorithm for mammography and how the wavelet based algorithm improves the imaging performance of digital mammography. They have also done a comparative study on multi-scale wavelet algorithm and other existing algorithms. But they could not explore the method directly to clinical mammography.

2. PROPOSED METHOD
Different steps involved in the proposed method are: ROI marking and alignment, wavelet packet decomposition, combining the coefficients by averaging and inverse wavelet transform with post processing techniques. This procedure is used for images where ROI is not aligned. Initially mark the ROI in first image, then the ROI of the remaining images will get automatically aligned to this. As the next step find the wavelet packet coefficients for all the images. Combine these wavelet packet coefficients so that we get the coefficients for a single image. As the final step take the inverse wavelet packet transform to get the enhanced output image. For the comparison purpose various performance parameters are also calculated for the final enhanced image.

2.1 ROI Alignment
When a scene is captured multiple times there will be a relative motion between the scene and the camera. In such cases, it is required to register the images or align the ROI from the different images [11]. For this, the ROI is marked on the first image manually and extract that portion. This is called template image. To locate the ROI in all other images, a template matching approach is used [10]. Phase correlation method is used to find out the pixel distance between images. According to phase correlation method, a shift in the spatial domain results in a linear phase change in the frequency domain. The peak value of inverse Fourier transform of the phase correlation is given as,

\[ c = \max \left( F^{-1}q(u,v) \right) \]  

(1)

Once the peak value position is found, take out that part from the specific image and replace the pixels in that image with the pixels matching to the marked ROI in the first image. This is done for all the set of images. The main advantage of the phase correlation method is that the accuracy by which the peak value of correlation function can be detected. It provides coherent peak and some incoherent peaks. The main applications of phase correlation are pixel-pixel image co-registration, motion flow estimation and disparity mapping for stereo matching.

2.2 Wavelet Packet Transform
Using WPT the signal is analyzed in a basis which comprises both time and frequency information [7] [14]. Wavelet decomposition is used to analyze a signal at separate resolution levels. In the case of DWT[3] [15] [18], it is implemented by dividing each sequence into a component containing its approximated version, which is the low-frequency part and a component with the residual details, which is the high frequency part. This process is continued only for the low-pass branch of the tree. Wavelet Packet Transform is a generalization of the DWT, with a rich set of decomposition structures. WPT deals with the non-stationary of the data better than DWT. Compared to DWT, in Wavelet Packet Decomposition the signal is allowed to pass through filters[19] which results in approximate and detailed component, thereafter both approximation and detailed coefficients of each level is passed through a low pass and high pass filters in order to calculate the coefficients for the next level. So the high frequency data will not be lost. For n level decomposition, wavelet packet decomposition yields \( 2^n \) sets of coefficients, but DWT gives \( (n + 1) \) sets of coefficients. While taking a three level wavelet packet transform, 64 sets of coefficients will be obtained. Figure (1) shows three levels of WPT. S represents the input signal or image. A represents the approximation coefficients and D represents the detail coefficients. A1 shows the approximation coefficients in the first level and D1 shows the detail coefficients in the first level. Similarly A2, D2, A3 and D3 represents the approximation and detail coefficients in the second level. The main advantage of WPT is it helps in getting the optimal representation of the image.

![](image1.png)

**Fig. 1 Block Diagram of Wavelet Packet Transform**

2.3 Inverse Wavelet Packet Transform and Post Processing
After finding the WPT, the coefficients are combined by taking average of the input image coefficients, with a simple averaging technique, using the equation

\[ F(x,y) = \frac{X_1(x,y)+X_2(x,y)+\cdots+X_N(x,y)}{N} \]  

(2)

Where \( X_1(x,y) \) denotes the \( (x,y)^{th} \) WPT coefficient of the \( 1^{st} \) input image, \( X_2(x,y) \) depicts the \( (x,y)^{th} \) coefficient of the \( 2^{nd} \) input image and \( X_N(x,y) \) depicts the \( (x,y)^{th} \) WPT coefficient of the \( N^{th} \) input image. \( N \) denotes the number of input images. This is found for three levels of WPT there are 64 sets of coefficients. Take the inverse wavelet packet transform of these \( F(x,y) \) coefficients using the equation(3) gives the reconstructed image.

\[ I_f = IWPT(F) \]  

(3)
Post processing consists of an unsharp masking which is used here to sharpen the edges of the image. Here an unsharp (smoothed) version of an image is subtracted from the original image. It is done by blurring the Original image, then the blurred image is subtracted from the original image which gives the mask and finally the mask is added with original image so that we get the final enhanced output image.

### 2.4 Performance comparison Parameters
Here the no - reference parameters - Spatial Frequency and Standard Deviation [12], where the quality metric is calculated from the enhanced output image, without using a reference image, are calculated. Spatial frequency (SF) shows how the image intensity level varies. As the value of SF increases, better will be the enhancement technique. Standard Deviation (SD) shows change in pixel value from the mean value. As the SD increases, better the enhancement technique.

### 3 RESULTS AND DISCUSSIONS
Here four frames from a video of a moving vehicle moving on a hot road is taken. The quality of these frames is less since it is distorted by atmospheric turbulence. The Figure 2(a), Figure 2(b), Figure 2(c) and Figure 2(d) are the four input images considered.

The ROI in the 1st image is marked manually as given in Figure 3. The ROI is marked in the gray scale version of the first image in order to perfectly obtain the coordinates. After marking this, with this as reference subsequently mark ROIs in the remaining images.

ROI marked four images are given in figure 4(a), figure 4(b), figure 4(c) and figure 4(d), where the ROI is marked using rectangular box. The rectangular box is drawn where the phase correlation gives maximum value.

### Table 1
Performance comparison parameters

<table>
<thead>
<tr>
<th>Enhancement Method</th>
<th>Standard Deviation</th>
<th>Spatial Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPT Haar</td>
<td>33.502</td>
<td>19.2494</td>
</tr>
<tr>
<td>WPT Daubechies</td>
<td>33.4787</td>
<td>19.1285</td>
</tr>
<tr>
<td>DWT Haar</td>
<td>29.2907</td>
<td>11.1285</td>
</tr>
<tr>
<td>DWT Daubechies</td>
<td>29.2722</td>
<td>11.1205</td>
</tr>
<tr>
<td>Guided Filtering</td>
<td>26.9358</td>
<td>9.781</td>
</tr>
</tbody>
</table>

### 4 CONCLUSION AND FUTURE WORK
This paper introduced a new image enhancement method for the images distorted due to atmospheric turbulence, when the
multiple images of the same scene are captured with the ROIs not aligned. It shows how WPT is used for the image enhancement and by comparing the values of standard deviation and spatial frequency it is understood that this method gives better results. Images of a moving car in a hot road, where the atmospheric turbulence effect is more, is used for the experiment. These images have single ROI and the method is for the images with single ROI. The work can be extended for images with multiple Regions of interest.

5 REFERENCES


