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Key Challenges and Resolutions for Atmospheric Turbulence Effect Removal

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Abstract

Long distance images suffer from atmospheric turbulence that arises due to random variation in refractive index of the medium. It produces geometric distortion, space-time-varying blur and motion blur in observed images. To overcome these problems and obtain high quality latent image, researchers have proposed various techniques such as adaptive optics, image selection and fusion, and multi-frame image processing techniques. The hardware based adaptive optics method measures atmospheric distortion in the incoming light from a distant object and sends electronic signal to deformable mirror, which varies its shape rapidly to correct the distortion. Image selection and fusion method also called 'Lucky imaging' selects and fuses superior frames from observed images on sharpness basis. Multi-frame image processing method first registers all observed frames and processes it with different reconstruction algorithms to obtain endmost result. This paper critically reviews some of the existing methods for removing atmospheric turbulence distortion for real-time image processing. The specific applications of some of these methods are also presented.

***Keywords**: Image processing, atmospheric turbulence, algorithms, deblurring, dehazing*

1. Introduction

The conditions of air in the atmosphere are non-uniform and heterogeneous. Air temperature above the land surface that receives direct sunlight becomes hot. The denser cool air above this hot air changes its refractive index, continuously and non-uniformly. The air pressure, humidity, carbon dioxide level, and air dust density have major impact on the refraction index of air. Due to atmospheric absorption and scattering, images of distant scenes degrade by turbulent motions and turbid medium (such as particles, water droplets, *etc.*,). These effects produce geometric distortion, noise, space-time-varying blur, motion blur and out of focus blur (during strong turbulence). Thus, images detail such as contrast, sharpness etc. are spoiled by turbulence and heat shimmer effects.

To reduce these effects and obtain noise free images, various image restoration algorithms and filters are applied. Various restoration algorithms are used such as Poisson maximum a posteriori (MAP), Van Cittert, Landweber, Total Variation, Expectation-maximization (E-M) and Tikhonov-Miller and filters are mostly employed includes Inverse, Wiener, Kalman, Spatial domain Gaussian smoothing, Median, Mean, Lee, frequency domain Gaussian low pass filters.

Several researchers, 1998-2017 [1-25], proposed techniques such as adaptive optics, image selection and fusion/lucky imaging and multi-frame image processing method for reduction of the atmospheric turbulence effects in distorted images. Adaptive optics

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method requires reference object near target to find how it degrades from its expected looks. In addition, it is hard to estimate optical transfer function (OTF) and restore deblurred image due to random nature of turbulence. To recover final image, [6-10] applied different filters like inverse, wiener, wavelet, kalman, *etc.*, on observed degraded images to remove noise and blur effects. Another class of technique utilized image selection and fusion methods [11-19] to alleviate geometric distortion and blur from a short-exposure degraded sequence. The 'lucky frame' method determines superior frames among number of image frames on sharpness basis that are not distorted much due to turbulence. The final output image is produced by fusing these lucky frames. However, 'lucky frame' method suffers due to lower probability of getting a whole high-quality frame. Therefore, another method of 'lucky regions' where sharper regions from short-exposure images are selected and fused so that high quality output image is recovered. Similar to 'lucky frame' method, this method also suffers due to less chances of receiving all high-quality regions. This method suffers due to requirement of large number frames that makes it unsuitable for long-exposure degraded images because of motion blur.

Recently, a new approach based on multi-frame image processing is proposed for restoring high-quality latent image from sequence of observed images distorted by atmospheric turbulence [3], [4] and [20-25]. This method uses diffeomorphic warping and image sharpening techniques to reduce geometric distortions and space-time-varying blur in degraded images. It includes high performance non-rigid image registration technique, various deblurring and denoising algorithm and different image reconstruction frameworks such as super-resolution method, Bayesian image reconstruction, near-diffraction-limited image reconstruction, blind space-invariant deconvolution algorithms. Non-rigid image registration technique is used to register the observed frames to suppress geometric distortions. The deblurring and denoising algorithms work to remove different types of blur and noise. The image reconstruction method restores a final output. Hirsch *et al*. [1] presented an efficient filter flow (EFF) method based on the space varying multi-frame blind deconvolution algorithm. It resulted in deblurring artifacts due to the sensor noise effect. Shimiuz *et al*. [2] also used non-rigid registration technique with B-spline function and super-resolution reconstruction method to recover high-resolution latent image. The drawback of this method is the limitation to estimate exact point spread function (PSF) for space-varying blur. The point spread function (PSF) is imaging system's impulse response to a point source that describes blur (spread) of the point object. Zhu *et al.* [3] solved these problems by introducing space-invariant deconvolution algorithm for reducing geometric distortion, space-time-varying blur using B-spline non-rigid registration and temporal regression methods. However, this method shows poor registration result during strong turbulence because reference image is obtained by temporal mean of the observed frames. In addition, assumption of scene, image sensor to be static and inherent noise during registration error limits its use. In 2014, Xie *et al*. [4] worked on strong atmospheric turbulence and presented a combination of variational model and distortion-driven spatial temporal kernel regression method thereby obtaining better quantitatively results in terms of peak signal-to-noise ratio (PSNR) and structural similarity (SSIM) compared to other methods. Later on, Gibson *et al.* [5] introduced contrast enhancement and turbulence mitigation (CETM) method using bicubic interpolation instead of B-spline interpolation model for registration. The proposed method utilized contrast enhancement algorithm for removing fog along with atmospheric turbulence.

This paper technically reviews different techniques for removing atmospheric turbulence or heat shimmer effects in long range imaging system. This paper is organized as follows: Section 1 briefs about the recent work carried out till date, Section 2 discusses the mathematical modeling of atmospheric turbulence effect in distant scenes. Sections 3-5 discuss a brief technical review of different techniques such as adaptive optics, image selection and fusion and multi-frame image processing techniques. Section 6 presents specific applications of the methods discussed in section 3-5. Finally, Section 7 draws a brief summary of this paper.

2. Mathematical Model

Atmospheric Turbulence effects in long distant images make it extremely difficult to interpret information from the degraded images. Hence, there has been significant research activity attempting to faithfully reconstruct this useful information using various methods. In practice, the perfect solution is however impossible, since the problem is ill-posed, despite this imaging process with atmospheric turbulence can be described by the following mathematical expression, considering the scene and image sensor to be static [3].

$$O_k = B_k D_k Z + n_k \qquad (1)$$

Where o_k is k^{th} observed frame and Z is the ideal image. The blurring matrix B_k represents space-varying point spread function that includes blur and motion effects. The deformation matrix D_k represents space-invariant diffraction limited PSF and n_k represents additive noise. In order to remove these atmospheric turbulence effects block diagram is shown in Figure 1. We present a brief technical review of different techniques such as adaptive optics, image selection, fusion and multi-frame image processing techniques in Sections 3-5.

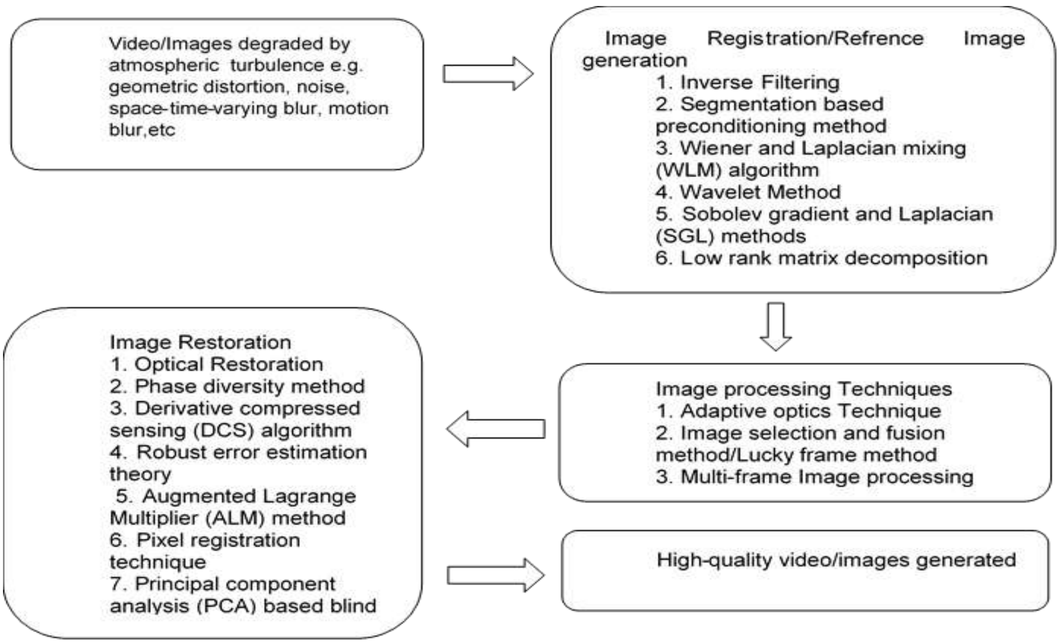


Figure1. Block Diagram for Atmospheric Turbulence effect removal Techniques

3. Adaptive Optics Techniques

Earlier, Sondhi [6] reviewed space domain and spatial-frequency domain methods for restoring images distorted by noise and space-invariant blur only. The author reviewed usage of inverse filtering and optical restoration of long-term turbulence distorted images. The various investigators restoration discussed by Sondhi [6] limits because they considered synthetic turbulence, assumed value of signal-to-noise ratio, blurring due to linear motion and considered absence of noise in degraded images. Paxman *et al.* [7] used phase diversity method for restoring near-diffraction limited imaging. The authors used a parametric model for space-variant blur function with multiple phase screens instead of space-invariant blur as reported by [6]. Nagy *et al.* [8] demonstrated the use of segmentation based preconditioning method along with Total Variation minimization denoising algorithm for optical images. The author's showed enhancement of optical image quality through space-varying regularization approach and iterative post-processing of image.

Previously, cross correlation technique was applied iteratively to estimate warping function for reducing motion blur. This technique requires much time and computational efforts. To overcome these drawbacks and to improve accuracy, Clyde *et al.* [9] presented iterative usage of gradient technique to estimate warping function of each individual frame to remove random shifts at each point in distant scene images as shown in Figure 2. The authors solved large shifts aliasing problem and instability due to noise by estimating optical flow via a gradient technique. This technique reduces motion blur by providing sub-pixel displacement estimation in time varying images.

Later on, Avidor *et al.* [10] proposed a method for reconstructing turbulence free single image and video from static, dynamic scene and static, moving camera. The authors presented a mathematical scheme that estimate optical flow between turbulence distorted images. The adaptive optics technique requires reference image or star for correcting wavefront phase distortions that is difficult to find especially in astronomical imaging. It also needs prediction of optical transfer function for restoring deblurred image, which is difficult to find because of random nature of turbulence. It is also expensive, time consuming and requires more computational efforts.

(a) (b)

Figure 2. (a) Average of Degraded Truck Image Sequence before Processing (b) Final Result obtained after Applying Gradient Approach [9]

4. Selection and Fusion Method

Applying another class of approach, Whatmough [11] demonstrated video resolution enhancement methods by considering different cases of moving objects like general and slow motion objects. Since resolution of video and images degrade by motion blur or optical blur, the author used wiener-filtering approach with regularized minimum mean square error (MSE) reconstruction for slow moving object. The author also used wavelet-based approach with regularized reconstruction for general and unknown motion of object as shown in Figure 3.

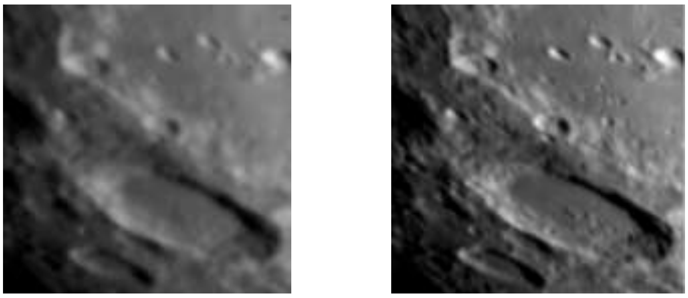
Figure 3. Enhancement of Whole Image with Different Moving Objects [11]

Lemaitre *et al.* [12] presented a hybrid method combining wiener filter and Laplacian regularization resulting in wiener and Laplacian mixing (WLM) algorithm for removing atmospheric turbulence effects especially on infrared sequences. For local processing of each frame of a sequence, wiener filter results in removing blur and obtaining clear edges. The Laplacian regularization results in noise removal and restoring a clear image.

Later on, Anantrasirichai *et al.* [13] introduced complex wavelet fusion for atmospheric turbulence (CLEAR) algorithm for attenuating atmospheric turbulence effects on observed images. The authors used dual tree complex wavelet transform (DT-CWT) to bring out details about objects from region of interest (ROI) by selecting effective frames and applying image fusion. This algorithm minimizes space-varying distortion and reduces haze through contrast enhancement.

Vorontsov *et al*. [14] presented synthetic imaging technique for restoring short exposure images by fusion of local information degraded by anisoplanatic conditions. The anisoplanatic imaging conditions causes phase distortion between different points of the object view through turbulent medium. The authors also combined processing of multiframe alignment, filtering and fusion of selected focused regions from observed frames to produce high quality frame free from atmospheric turbulence. The authors used robust error estimation theory for fusion of selective information observed from multi-frames. The edge map based correlation method process alignment of interframe shifts. The anisotropic gain function used with fusion rate is the variation between Gaussian smoothed-edge maps of input frame and the developed synthetic output frame. The nonlinear PDE with anisotropic gain function process filtering and fusion of selected focused regions from each observed frame.

Zhang *et al.* [15] demonstrated restoration of astronomical images affected by rapidly changing turbulence through lucky imaging system. This method involves best frame selection, alignment and co-addition with better angular resolution. For the best frame selection, authors used Strehl ratio in case of guide star in the image and Fisher information or Sobel operator for no guide star as shown in Figure 4. Large value of fisher information (F) results in clear image and small value of F results in blurred image. Recently, Lou *et al*. [16] presented a combination of Sobolev gradient and Laplacian (SGL) methods for video sequence stabilization and reconstruction from atmospheric turbulence by estimating scene's radiance. A single high quality latent image is recovered by 'Lucky region' method as shown in Figure 5. The deblurring is done by the Sobolev gradient method while temporal oscillations are removed using Laplacian method. Different from earlier approaches, Chan *et al.* [17] presented algorithm for processing video not as sequence of images but as space–time volume. The authors applied an Augmented Lagrangian method and alternating direction method for least squares minimization with Total Variation regularization. However, the scope of this algorithm is limited to weak hot air turbulence only.



(a) (b)

Figure 4. Moon surface image with degraded fine details (a) Original and (b) After processing by lucky imaging [15]

(a) (b)

Figure 5. (a) Video Sequence of a target distorted by heat shimmer using one frame and (b) Final result obtained after applying SGL method result [16]

For first time, Gibson *et al*. [5] proposed contrast enhancement and turbulence mitigation (CETM) method for removing both fog and atmospheric turbulence effects in distant scene images. The 2D median filter is used for image denoising and locally adaptive wiener defogging method is used to defog and to enhance the contrast image. Minimum output sum of squared error (MOSSE) and optical flow method estimates global and local motion vector respectively, for image alignment. Finally, to remove atmospheric blur and image alignment errors long exposure optical transfer function (OTF) is estimated. The authors used Turbulence Mitigation Metric (TMM) an objective measure to analyze mitigation of turbulence in time and obtain true image with temporal consistency in each color channel. The defogged and turbulence mitigated image by CETM method is shown in Figure 6. Oreifej *et al.* [18] introduced a new approach for both removing turbulence mitigation and detecting moving object in videos distorted by atmospheric turbulence. The authors used low rank matrix decomposition approach for disintegrating video sequence matrix into background, turbulence and object. The iterative uses of Augmented Lagrange Multiplier (ALM) method provide optimal solution for low rank matrix decomposition by minimizing Augmented Lagrangian function. Law *et al.* [19] produced a final high angular resolution image by joining Lucky imaging and adaptive optics system (Lucky +AO). This hybrid method provides better results than speckle imaging systems.

(a) (b)

Figure 6. (a) Foggy image and (b) Defogged image by Wiener defogging method [5]

The speckle imaging is astronomical imaging method that uses shift-and-add or speckle interferometry method to remove effects of astronomical objects blurring due to atmospheric turbulence. However, speckle-imaging method limits due to limited resolution of a telescope. Thus, authors applied hybrid method (Lucky + AO) to obtain high angular resolution image.

5. Multi frame image processing method

Previously, researchers used wave front sensing and multi-frame blind deconvolution super-resolution algorithm based on bayesian maximum–likelihood formulation for recovering short exposure images distorted by atmospheric turbulence. In blind deconvolution algorithm, the optical transfer function (OTF) is unknown and estimated for each frame. In real-time image processing wave front, sensing shows better results than blind deconvolution method.

Considering both multichannel and single channel cases for restoration of atmospheric turbulence distorted images, Li *et al.* [20] presented principal component analysis (PCA) based blind deconvolution method. The PCA has maximum variance corresponding to high-frequency component in an image with optimal estimation of true image. The authors compared this approach with adaptive Lucy-Richardson (LR) maximum-likelihood algorithm. It was observed that the PCA based approach requires less computational time also reduces noise and removes ringing effects more efficiently than LR algorithm. However, this approach lack in providing phase information for better restoration. This drawback is eliminated using second–order central moment or kurtosis minimization (KM). Later on, Li [20] also introduced an improved blur identification or blind image deconvolution method by kurtosis minimization using phase correlation. This method iteratively used wiener filter for image deblurring and minimal kurtosis i.e. normalized fourth central moment as blur identification parameter for final deblurred image. The authors compared this method with other restoration methods like generalized cross-validation (GCV) and Self-deconvolving data reconstruction algorithm (SeDDaRA). The KM method result shows sharp image with amplified high frequency components while GCV and SeDDaA displayed underblurred and overblurred (unnatural) image respectively. The KM method is based on observed statistics of images and has a limitation that the profile needs to be concave, which is generally not true for all images. This drawback is eliminated by subdividing image into overlapped sub-images and the parameter is estimated from kurtosis statistics. Subsequently, a second-order central moment (SOCM) minimization method was also compared with GCV and KM methods. This method iteratively used wiener filter for image deblurring and minimal SOCM as blur identification parameter for final deblurred image. Since, this method is limited to images with finite-extent objects with a uniform background. The authors estimated noise and signal variance from object and background regions respectively. Overcoming drawbacks of the GCV method being sensitive to noise, the KM method shows unpredictable kurtosis statistics for the whole image, the SOCM represented highest peak signal-to-noise ratio (PSNR) with lowest computational time for restoring astronomical images distorted by atmospheric turbulence.

Farsiu *et al*. [21] presented multi-frame motion estimation method considering global consistency constraints conditions in image sequences. This method is applicable to all motion model given by Whatmough [11] with high accuracy and reliability. It also alleviate the effects of outliers, noise and hence effective for multi-frame super resolution applications. As reported by Paxman [7], Bardsley *et al.* [22] presented phase diversity based method for image restoration from space-varying blur. This method sections the image into sequence of frames which have unknown spatially invariant PSFs. To calculate phase in each region, the authors used phase diversity based blind deconvolution using L-BFGS optimization algorithm and Nagy and O'Leary technique reconstruct the final image. To recover image sequence from optical turbulence, Shimiuz [2] proposed multi-frame super-resolution reconstruction method using an area based non-rigid deformation model with B-Spline function for texture-less or noisy region. Global motion (camera or object motion) and local motion (residual motion) deform distant observed images. The author has used translational or affine motion model, zero-mean Gaussian model to remove global motion and local motion respectively. However, these models fail to estimate exact PSFs.

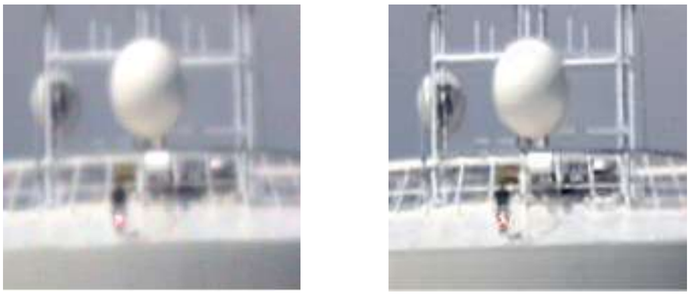
To solve both blind and non-blind deconvolution problems, such as camera motion blur, image noise and ringing artifacts, Shan *et al.* [23] proposed a unified probabilistic model. The iterative optimization scheme reweights the relative strength of the model that alternates between blur kernel estimation and unblurred image restoration until convergence. This approach results in high-quality image that maintains image structures, fine edge details and removes artifacts as shown in Figure 7. Similarly, the space-variant blind deconvolution algorithm using overlap-add (OLA) method was proposed by Hirsch [1] that also limits by diffraction-limited blur and ringing effects. In OLA, method image is divided into overlap patches, process each patch with space-variant linear filter and add the processed patches to recover final output image. However, the final output alleviates non-uniform atmospheric turbulence effects but this method fails to estimate diffraction limited blur and remove ringing artifacts in images. However, this method finds application in astronomy and medical imaging.

To overcome the limitations of earlier attempts [23], Hirsch [1] approached with a hybrid model combining projective motion path blur model (PMPB model) with efficient filter flow (EFF) model for fast removal of non- uniform blur by camera shake. This hybrid model benefits since it requires less computational time and provides efficient results. However, this approach cannot be applied to moving objects and depth variation images. Zhu [3] also used multi-frame image reconstruction approach to obtain deblurred videos affected by heat shimmer as reported by [2]. The authors used B-spline non-rigid registration algorithm with fast Gauss Newton method to register each observed frame to suppress geometric distortion. L_1 Norm with bilateral total variation (BTV) regularization prior was applied in Bayesian reconstruction algorithm to alleviate atmospheric turbulence effects in long exposure and noisy videos. However, assumption of space-time-invariant PSFs in reconstruction stage limits its performance.

(a) **(b)**

Figure 7. Image captured with hand held camera (a) Blurred image due to camera shake and (b) Blind deconvolution result [23]

Using the same methodologies, Zhu [3] presented new framework to previous attempts by using B-Spline non- rigid registration with fusion process and blind deconvolution method. The obtained output image is free from geometric distortion along with diffraction-limited blur as shown in Figure 8. However, this approach assumed space-time-invariant near diffraction limited PSFs in fusion step. Later on, Zhu proposed an improved method for removing geometric distortion, space-time-varying blur and diffraction limited blur. The authors applied B-spline based non-rigid image registration with temporal kernel regression method. The final deblurred output is obtained by blind deconvolution method as shown in Figure 9. The drawback of this method lies in poor registration during strong turbulence results in noisy output. Recently, Caliskan *et al*. [24] presented optical flow based registration technique for degraded image sequence along with patch wise multi-frame reconstruction method to stitch the registered images. The final high-quality deblurred image is obtained using blind deconvolution method.



(a) **(b)**

Figure 8. Water Tower video distorted by atmospheric turbulence (a) One Observed Frame and (b) Fusion result [3]

Lau *et al.* [25] observed algorithm that obtain a sharp reference image using energy function. The authors applied Robust Principal Component Analysis (RPCA) in order to obtain subsampled image sequence with sharp and mild distorted image frames. This algorithm produces near real time stabilized video with better-aligned images using blind deconvolution as compared with exiting algorithms as shown in Figure10. However, cost factor results in its drawback. Later on, Lau worked iteratively on reducing energy model for joint subsampling of frames and extracting a clear reconstructed image without artifacts. This method applied image restoring and image subsampling (IRIS), low rank image restoring and image subsampling (LIRIS) and total variation image restoring and image subsampling (TVIRIS) models for removing atmospheric turbulence from degraded video. Another advantage observed for this method is effective computational time of less than 2 seconds for 100 degraded frames. This method can be utilized as preparatory step along with other methods.

(a) (b)

Figure 9. Moon Surface video distorted by atmospheric turbulence (a) One Observed Frame and (b) Blind Deconvolution result [3]

(a) (b)

Figure 10. Comparison of results on the Car front sequence (a) Ground Truth and (b) RPCA result [25]

Comparison among three image-processing techniques is given in Table 1. The multi-frame image processing method shows better results than other techniques but limits themselves in strong atmospheric turbulence and when medium changes to water. However, results obtained by this method are comparatively better but needs further adaptation.

Table 1. Comparison of Three Image Processing Techniques

Sr. No.	Factors	Adaptive Optics Technique	Image Selection and Fusion Technique	Multi-frame Image processing Technique
1	Time and Computational Efforts	Very High	Medium	Low
2.	Artifacts Removal	Low	Average	Very Efficient
3.	Image Quality	Not too Good	Good	Better
4.	Motion Blur Removal	No	No	Yes

6. Specific Applications of Atmospheric Turbulence Removal Techniques

6.1. ASTRONOMY

Many space endeavors utilize state-of-the-art image processing tools. Lucky imaging is not a new idea but is a remarkably effective technique for delivering near-diffraction-limited imaging in the visible range on ground-based telescopes. If images are taken fast enough to freeze the motion caused by the turbulence it is found that a significant number of frames are very sharp indeed, where the statistical fluctuations are minimal. By combining these sharp images, a much better image is produced. AOLI "Adaptive Optics Lucky Imager" is an instrument with extension of the adaptive optics already used in ground telescopes. It delivers near-perfect images, by virtually eliminating the effect of turbulence in the Earth's atmosphere, and uses much fainter reference stars than is typically possible with adaptive optics. Multi-frame blind deconvolution method is used for improving the resolving power of ground-based telescopes used for space surveillance.

6.2 MILITARY

In military, it is crucial importance to have large recognition range. However, atmospheric turbulence effects resulting in blurred images degrade the recognition range especially for 'land-to-land' observation. Many software and hardware approaches are applied to recover high-resolution deblurred images. In software method such as image selection and fusion method, frames with region of interest (ROI) are selected on sharpness basis and fused, to produce high-resolution deblurred images. In multi-frame image, averaging fixed number of frames calculates processing reference frame over time and estimates optical flow through image registration method and final image is produced using super-resolution (SR) reconstruction method. These solutions are flexible robust, fast, produce state-of-the-art results and can be implemented in real time. In this case, digital post processing is often employed to obtain images free from atmospheric turbulence.

6.3 REMOTE SENSING

Remote sensing field analyzes, measures and interprets scenes at a distance. Thus, remote sensing images are subjected to blurring due to the rapidly changing index of refraction of the medium, the finite broadcast bandwidth and the object motion. The blurring effect is modeled by total modulation transfer function (MTF) or point spread function (PSF). Atmospheric turbulence removal techniques such as Blind deconvolution or restoration method is applied to remove blurring effect in these images.

6.4 BIOMEDICAL IMAGING

Medical imagery is one of the fields that have made use of images since the earliest days. The image fusion is a powerful and frequent tool in medical imaging like simultaneous evaluation of CT (computer tomography), NMR (nuclear magnetic resonance) and PET (positron emission tomography) images, where a set of images of the same scene taken by the same sensor but from different viewpoints is fused to obtain an image with higher resolution or to recover the 3-D representation of the scene. Image deconvolution also restores objects that are distorted by medical imaging systems such as ultrasound, X-rays, magnetic resonance, scanners, etc.

6.5 VISUALIZATION

In imaging system, poor visibility conditions such as rain, fog, smoke and haze typically limit the range, soundness and effectiveness of still images and video systems. Several visual information-processing groups such as Weather Forecasters and Air Traffic Controllers have therefore developed image restoration technologies with different concepts with direct applications on the problem of poor visibility conditions.

7. Conclusion

This paper dealt in different techniques for removing atmospheric turbulence or heat shimmer effects in long range imaging system. The methods include adaptive optics, image selection and fusion, and multi-frame image processing techniques. The best choice among these methods is inherently application-dependent. The adaptive optics method reduces effects of wavefront distortions due to atmospheric turbulence on distant scenes by sending electronic signals to deformable mirror that correct the wavefront errors and recover latent image. Image selection and fusion method or Lucky imaging selects and fuses best frames from observed imageson sharpness basis. While multi-frame image processing method first registers all observed frames, processes these frames by using different reconstruction algorithms, and obtain result. The future work aims at using this experimental study and applying it on hardware. It also aims for integrating some of these methods for greater performance on removing atmospheric turbulence.

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