AN ADAPTIVE APPROACH TO ELIMINATE ATMOSPHERIC SCINTILLATION IN LONG RANGE VISIBLE SEQUENCE

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Abstract: Atmospheric turbulence (scintillation) is a naturally occurring phenomenon that can severely limit the resolution of long distance optical and infrared sensors. It has been recognized that atmospheric turbulence degrades the quality of images and video sequences. Stationary objects being observed through the atmosphere can appear blurred and waver spatially as if they are in motion. This paper proposes an adaptive approach which recovers limitations of various state of the art algorithms such as scene changing situations and moving object disorders. Existing Control Grid Interpolation (CGI) approximates accurate motion vectors to generate a geometrically correct frame using certain reference frames. However, for high scintillation sequences, existing CGI doesn't mitigate scintillations completely. The proposed approach handles the above limitation with additional features of frame validation and object recovery. The proposed method is computed on a standard dataset (OTIS). Experimental Results prove that the proposed approach provides higher accuracy based on standard performance measures such as MSE, PSNR and SSIM.

Key words: Atmospheric turbulence, Registration, motion vector calculation, MSE, PSNR, SSIM

1. INTRODUCTION

Atmospheric turbulence frequently interferes with visible and infrared imaging systems [1]. The heat in the air forms horizontal layers. Increasing the variance in temperature results in faster and more changes in the refractive index of air [2]. As a result, the refractive index changes under the effects of turbulent air flow and changes in temperature, air particle density, humidity, and carbon dioxide levels, and light is refracted by so many layers of turbulence [3].There are several reasons for the image captured through the camera to get blurred. This mainly occurs due to change in the refractive index of light due to the motion of wind [4]. Another reason, causing it, is the varying temperature or a heat wave above the ground surface, which causes the image to appear blurred [5].

Due to the effect of turbulence in the atmosphere, the scene observed and captured from a long distant camera gets ill-shapen [2]. The normal wavelet gets distorted and final result consists of blur, noise and aberration.

The simplest approach for mitigation is based on frames that use video frames sequentially [6]. In this method, each frame observed with turbulence is registered using a non-rigid image registration technique [6, 7]. Another approach is to remove distortion of turbulence without causing damage to the moving objects [8].

To mitigate the effect cause by turbulence is necessary for long distance image capturing. In Surveillance imaging [9] activities are monitored to observe changing information for purpose of managing or protection. In Medical image analysis [10], is the method and process by which the inner part of the body is produced for clinically and medically based analysis, as well as visually representing the function of certain organs or tissues. The proposed algorithm will remove the geometric deformation of the image and produce quality image. Sprinkling and optical turbulence associated with refractive index oscillations severely affects underwater imaging [11].

The rest of the paper is designed in the following manner. The related work is described in Section 2 and the proposed method is set out in Section 3. The simulation results and performance evaluation parameters in Section 4. Finally, Section 5 presents the conclusions.

2. RELATED WORK

In the last few years, several techniques have been proposed to eliminate the influence of atmospheric turbulence. Captured sequences contain geometric distortion and time varying blur [12]. These sequential video frames are utilized to mitigate the heat scintillation and to generate the turbulence free video sequence as output.

FRTAAS was proposed by Halder et al [13]. In this article, FRTAAS First Register Then Average And Subtract algorithm for image registration was proposed as a preliminary step for image restoration. In terms of time and accuracy a performance comparison is presented between the proposed restoration method and the earlier FRTAAS - based Minimum Sum of Squared Differences (MSSD) [14].

Time-averaged algorithm was proposed by Fraser et al. [15] is based on common techniques and components used in various algorithms to correct atmospheric turbulence. Heat scintillation is divided into two separate steps in this technique, i.e. distortion and blurring [16].

The Lucas-Kanade method was proposed by Lucas and Kanade [17]. The calculation of the optical flow of a sequence of images is still a challenge in video processing. There are no certain techniques that can produce sufficiently precise and dense optical flow. The Lucas-Kanade algorithm's local variable computation does not produce a good segmentation that indirectly affects the design of the optical flow. This approach estimates the difference in the independent Lucas-Kanade algorithm and the effect in combination with global variable such as the number of iterations and the Horn Schunck filters [18]. The comparison is based on the optical flow pattern, image motion segmentation and processing time. Image experiments have shown that the smoothing effect and iteration number together with filters improve the segments and optical flow by utilizing the partial derivative in the Lucas Kanad method in Schunck's Horn algorithm. This shows that intensity calculation affects the optical flow.

Control Grid Interpolation (CGI) was proposed by Sullivan and Baker [19]. The first step of the procedure is to increase image resolution by a factor of four using bilinear interpolation, the purpose of which is to facilitate sub-pixel accuracy. The motion field is obtained by segmenting the image into small contiguous square regions, the corners that form control points [20]. CGI is attractive for this application as it enables complex non transnational motion to be represented, unlike block matching, which is generally used in a conventional motion compensated for the estimation of motion vectors [21].

3. PROPOSED APPROACH

The main challenge, that traditional CGI faces is the partial scintillations which are still left out and distorted moving objects. To overcome both challenges, this paper proposes an adaptive CGI based technique that handles scene change situation and recovers small moving objects. The system flow of proposed approach is described in figure 1.

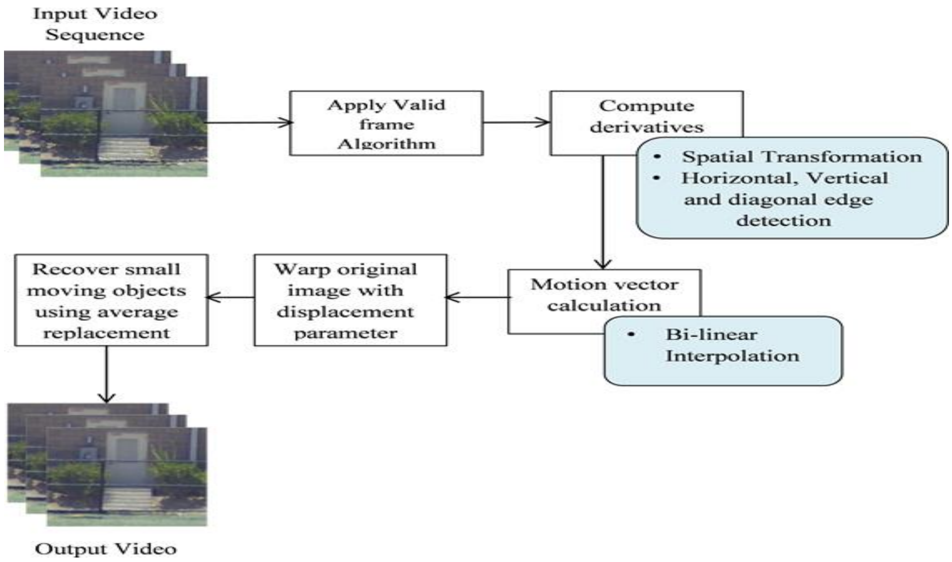


Fig. 1 System flow of proposed approach

Input Video Sequence: Input video means the video sequences influenced by atmospheric turbulence. There are visible band and infrared band of video frames. To make them turbulent free motion filed have to be find according to its type of frame. A standard OTIS dataset (Open Turbulent Image Set) [22] is used here to test the proposed approach containing sequences of visible bands.

Apply Valid Frame Algorithm: After retrieving the frames, the initial step is to validate the frame process. To handle a scene change situation, the proposed algorithm will first check whether reference frames are similar, or not, compared to the current frame. Experiments depict that if scene change situation occurs then after registration, it has some extra noise because of non-similar control points.

Compute Derivatives: It is a technique used for performing spatial transformation on image [23]. Three derivative matrix are used for transformation of image.

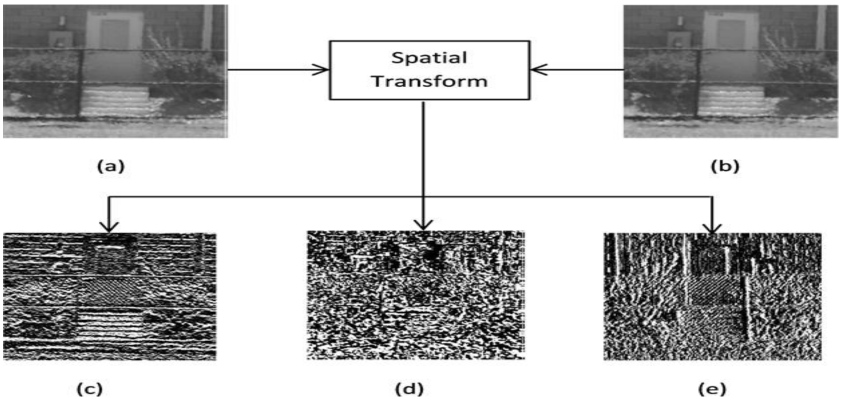


Fig. 2 (a) Simulated door gray scale frame 9, (b) Simulated door gray scale frame 10, (c) Horizontal mask, (d) Diagonal mask, (e) Vertical mask.

Two derivative filters estimate the horizontal and vertical part of motion vector. Third derivative estimates diagonal part of motion vector. The image is segmented into small continuous square region. The corners of each region are taken as control points. Using control points of each region, the motion vector is calculated.

Bi-linear interpolation of motion vector calculation : Similar to each separate region, the proposed motion estimation technique has its local motion vector. Pixel relationship between two frames within a region is described. The process for obtaining the motion vector is described below.

$$\begin{aligned} P1[i, j] &= P0[i + d1[i, j], j + d2[i, j]] \\ d1[i, j] &= \alpha1[i + d1, \alpha2i + \alpha3j + \alpha4ij] \\ d2[i, j] &= \beta1[i + d1, \beta2i + \beta3j + \beta4ij] \end{aligned} \quad (1)$$

Here *i* and *j* represents the pixel co-ordinates and *d1[i, j]* and *d2[i, j]* rep- resents the horizontal and vertical displacement of pixels between two frames P0 and P1 respectively. *d1[i, j]* and *d2[i, j]* are used to compute vector between the four control points enclosing each region. Therefore once the α and β parameters have been determined for each region, the intermediate motion vectors can be calculated. This provides a dense motion field of the turbulence.

Interpolation is a technique of creating new data points within the range of a discrete set of known data points. Here, interpolation is applied to the motion vector. Bilinear interpolation is used for estimating the in-between points of a vector. In bilinear interpolation, first, linear interpolation is performed in the X-direction. The resultant value is used for interpolating it in Y-direction. α and β are parameters which are determined for each segment of. R using bilinear interpolation. α and β can be calculated by minimizing.

$$\sum_{[i,j]\epsilon R} (P_1[i,j] = P_0[i + d_1[i,j], j + d_2][i,j]])^2 \quad (2)$$

Here using a Taylor series, (2) is approximated by

$$\sum_{[i,j]\in R}\left(P_0[i,j]-P_1[i,j]-\frac{\partial P_1[i,j]}{\partial_i}d_1[i,j]-\frac{\partial P_1[i,j]}{\partial_j}d_2[i,j]\right)^2 \quad (3)$$

The terms of high order are excluded from (3). Bi-linear final parameters can be estimated using the least square approach. Finally, motion filed is generated between the target frame and the reference frame.

Warp original image with displacement parameters: The estimated control points horizontal and vertical displacement between two frames will be warped with original image. Multiple reference frames are used to find displacement. Average displacement metrics is used to warp the turbulence motion from target frame.

Recovering Small Objects with Average Replacement Algorithm: If video or image sequence contains some moving objects, the final image has less information around moving objects due to interpolation. To recover this moving object, a primary step is to identify it. To identify moving object, the registered frame is subtracted from previous frame or original frame and the resulting matrix contains detail about shifted (moved) part. To recover the moving object, estimated moved pixels are replaced from the subtracted image to the registered image.

Output Video: At the end, a turbulence free video sequence is generated. This approach reduces the fluctuation caused by turbulence and also recover the small moving objects. The results of the novel CGI approach are showcased in following section.

4. SIMULATION RESULTS

To evaluate the performance of adaptive proposed approach, simulations are performed on Intel Core i5 - 4570 T with 2.90 GHz processor and 8 GB RAM in a MATLAB environment. Three sequences of the standard Open Turbulent Image Set (OTIS) [23] dataset were used to test the existing CGI and proposed adaptive CGI approach.

Fig 3 (a) represents the original input frame from the door sequences. Fig 3 (b) represent the output frame simulated using the existing CGI. The output is of good quality and geometrically less distorted in comparison with to input frame. Fig 3 (c) represents the output frame simulated using the proposed CGI. The experimental results of the proposed approach depicts that the geometric distortion is less with the existing CGI approach.

(a) (b) (c)

Fig. 3 (a) 10th observed frame of input door sequence, (b) Result of existing CGI, (c) Result of proposed CGI.

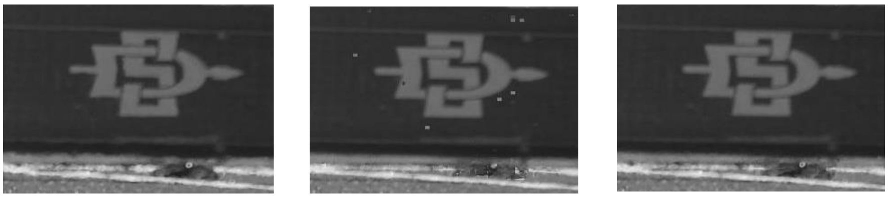
4.1. Recovering moving objects

If video or image sequence contains some moving objects, the final image has less information around moving objects due to interpolation. So there is a challenge to restrain the moving object from getting degraded. To overcome this challenge, a simple technique is implemented, which finds moving objects and adds those objects again in registered frame. This is achieved by identifying moving objects. To identify moving objects, a registered frame is subtracted from a previously registered frame or previous input frame. In difference image, the pixels of moving objects in the registered image are replaced by pixels of the input image.

In figure 4 and figure 5, the moving object (a toy car) disappeared in existing CGI Registration. In proposed CGI Registration approach the moving object was recovered.

(a) (b) (c)

Fig. 4 (a) 10th observed frame of input moving car3 sequence, (b) Result of the existing CGI, (c) Result of the proposed CGI.



(a) (b) (c)

Fig. 5 (a) 10th observed frame of input moving car2 sequence, (b) Result of the existing CGI, (c) Result of the proposed CGI.

5. PARAMETER RESULTS

After experimental simulation, the adaptive proposed approach is evaluated using standard parameters for measuring quantized efficiencies. There are certain parameters that can be used to check the similarity between images: MSE (mean square error), PSNR (Peak Signal to Noise Ratio) and SSIM (Structure Similarity Index Method).

MSE: The MSE is calculated between each frame in the output sequence of the algorithms and the original frame [24].

$$MSE = \frac{1}{mn}\sum_{x=0}^{m-1}\sum_{y=0}^{n-1}[I(x,y) - N(x,y)]^2 \quad (4)$$

Here I is the image intensity and N represents the noise present in the image frame.

PSNR: PSNR is one of the popular image quality metrics. The PSNR between two images A and B of size $m * n$ can be measured as below [25].

$$20.log_{10}MAX_i - 10.log_{10}MSE \quad (5)$$

where MAX_i is the maximum pixel value possible.

SSIM: The SSIM index is computed on different windows of an image. The measure between two windows with same dimensions is given as below [26].

$$SSIM = \frac{(2\mu_m\mu_n + w1)(2\mu_m\sigma_n + w_2)}{(\mu_m^2 + \mu_n^2 + w_1)(\sigma_m^2 + \sigma_n^2 + w_2)} \quad (6)$$

Here, the mean and variance of windows m and n are $\mu_m\mu_n$ and σ_m^2, σ_n^2 respectively, $\sigma_m n$ is the covariance of m and n.

The existing approach and proposed approach are evaluated on the above mentioned standard algorithms. The performance of both approach is showcased in Table 1.

As per the parameters results mentioned in Table 1, it can be clearly noted that the proposed algorithm shows efficient results and almost close with respect to the existing algorithm. It also recovers moving objects in contrast to the existing CGI approach. In turbulent video sequences with the same scene and with moving object, MSE, PSNR and SSIM values between consecutive frames represents the influence of turbulence. The MSE, PSNR and SSIM value calculation between consecutive frames of the results of CGI and the proposed approach can depict the efficient performance of the proposed approach.

Table 1. Performance evaluation of proposed approach with multiple dataset

Sequence Name	Technique	MSE	PSNR	SSIM
Input door sequence	Input sequence	0.0018	75.5565	0.7953
	Existing CGI	0.0015	76.7357	0.8577
	Proposed approach	**0.0008**	**78.8198**	**0.8659**
Moving Car 1 sequence	Input sequence	0.0014	76.5233	0.7936
	Existing CGI	0.0010	79.0013	0.8054

	Proposed approach	**0.0008**	**81.6052**	**0.8597**
Moving Car 3 sequence	Input sequence	0.0012	78.5362	0.7092
	Existing CGI	0.0007	79.3577	0.9366
	Proposed approach	**0.0008**	**81.0134**	**0.9402**

6. CONCLUSION

Atmospheric turbulence arises from a complex set of interrelated factors, such as wind velocity, temperature, elevation, sun intensity, and so on. While most algorithms had difficulty dealing with mitigation of turbulence in the scene, the existing CGI algorithm is shown to compensate for geometric distortions. However, it was found that a moving object (real motion) deteriorates after registration process. Hence, a new adaptive method is proposed to recover moving objects and to handle scene change situations. Proposed adaptive CGI achieves more accurate results than the existing CGI algorithm. The parameters measured clearly depict the superiority of the proposed method. This work can be enhanced for mitigation of turbulence in the scenarios where the scene is not static.

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