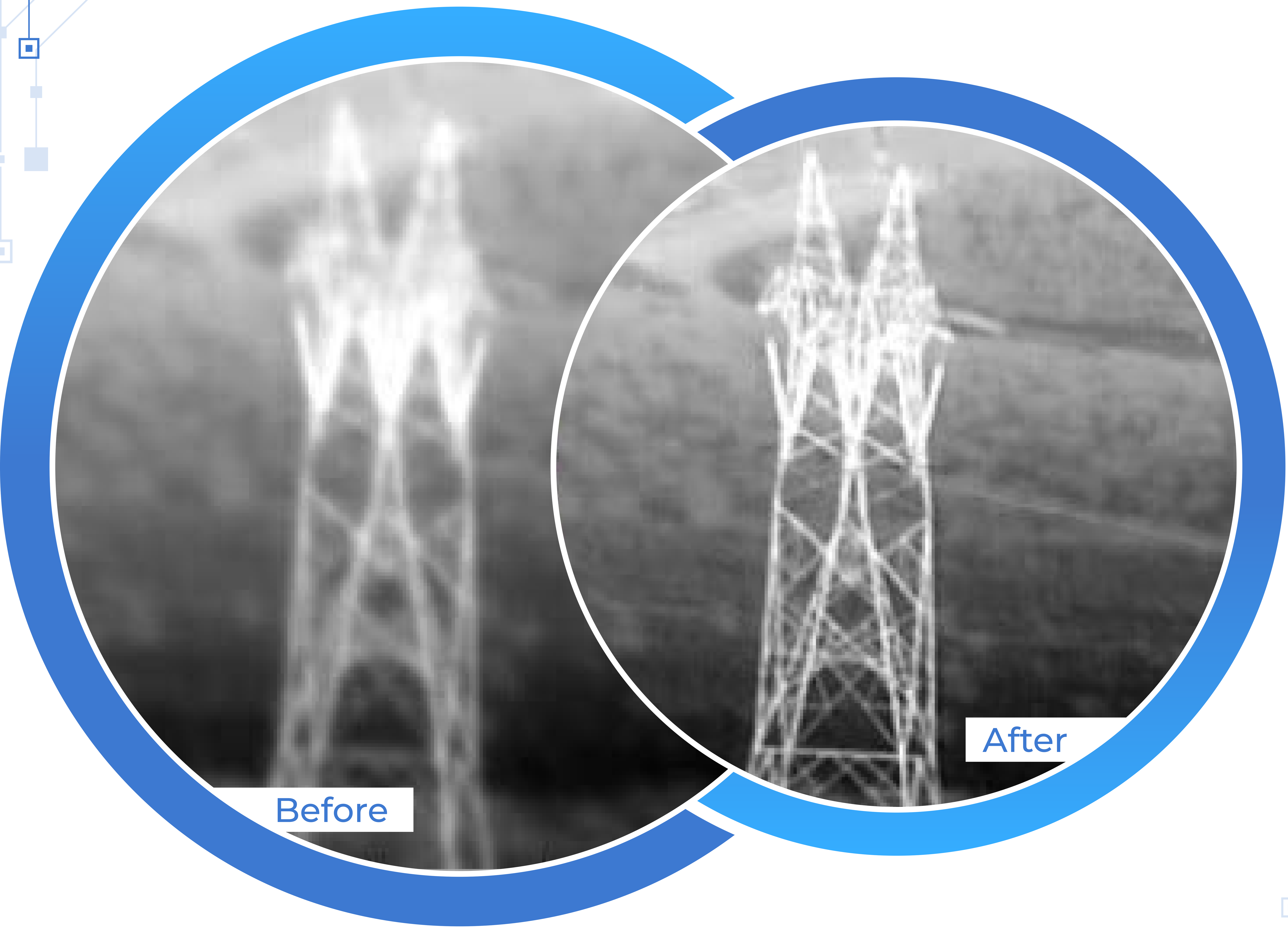
logic fruit Technologies



WHITEPAPER

A REAL-TIME ALGORITHM
for Atmospheric Turbulence Correction

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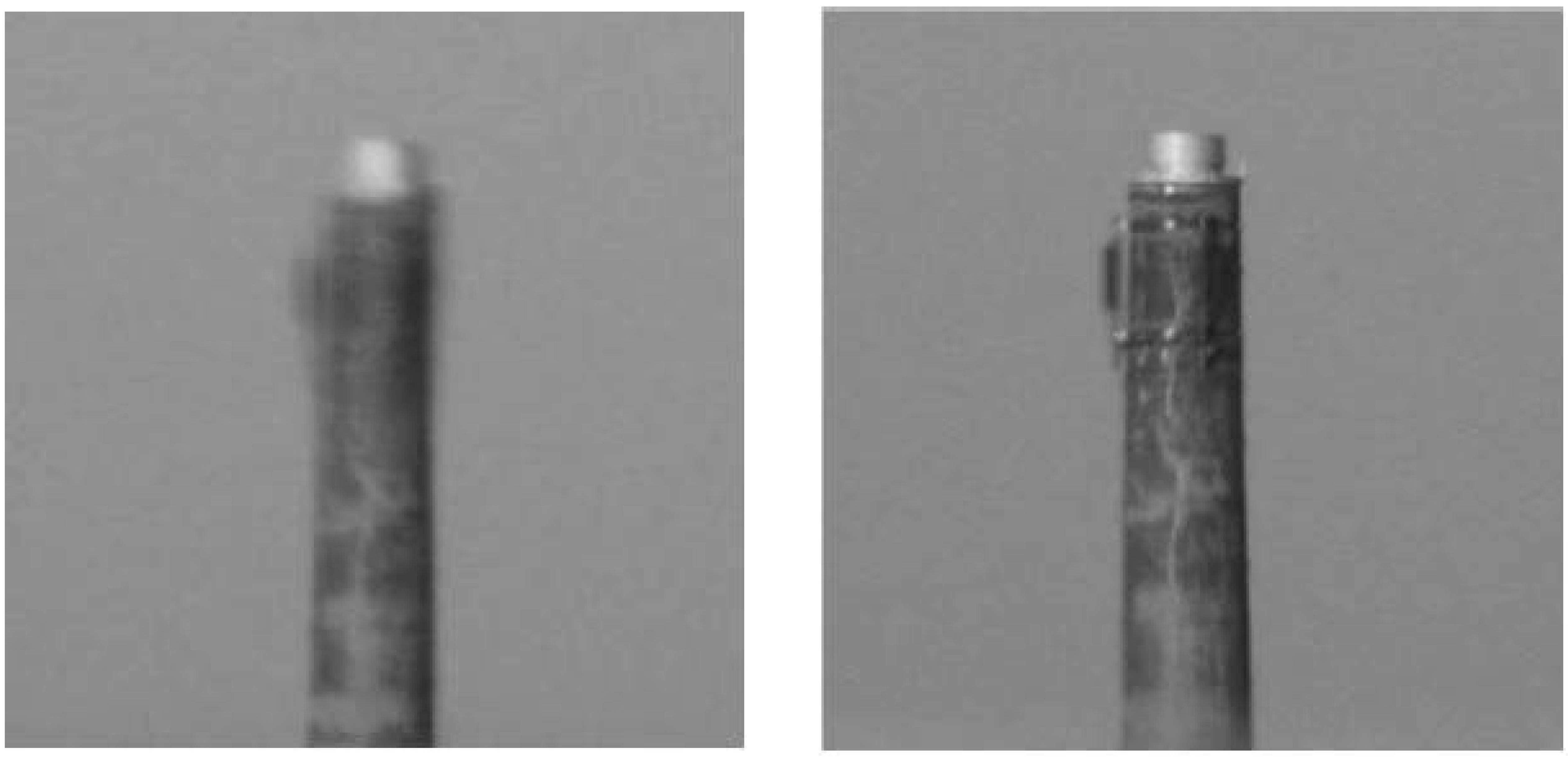
A Real-time Algorithm for Atmospheric Turbulence Correction

Overview

Atmospheric turbulence poses a significant problem in fields like long range surveillance and astronomy. This paper presents an algorithm for correcting atmospheric turbulence. This algorithm is capable of giving real-time performance, processing a 640x480 resolution frame at more than 30 FPS. This algorithm is useful in restoring videos from fixed cameras and videos having negligible background changes w.r.t foreground.

What is Atmospheric Turbulence?

Atmospheric turbulence is a phenomenon which causes object distortion and blurring effect in long range image sequence. It occurs due to the index of refraction of air decreasing with an increase in air temperature, causing objects to appear blurred and waver slowly in a quasi-periodic fashion. Fig. 1 below shows the effect of atmospheric turbulence.



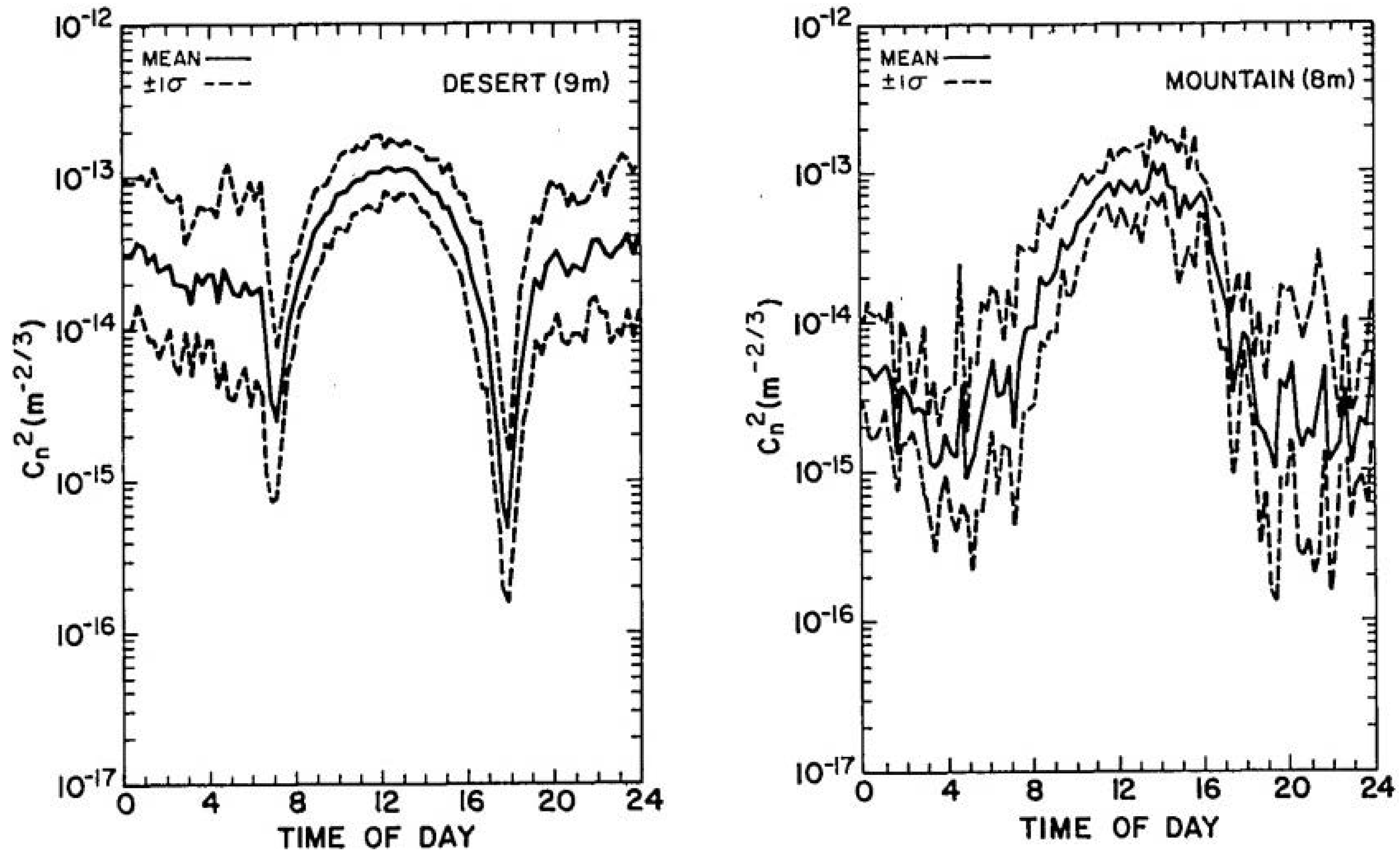
(a) (b)

Figure 1: (a) Original Image (b) Image with Atmospheric Turbulence

Atmospheric Turbulence is governed by a parameter known as Refractive Index Structure Parameter C_n^2.

Fig. 2 below show variation in C_n^2 value during whole day.

Fig. 3 shows the effect of solar insolation on C_n^2.



(a) (b)

Figure 2: Averaged ***C_n^2*** *measured for a day (a) in Desert (b) in Mountain*

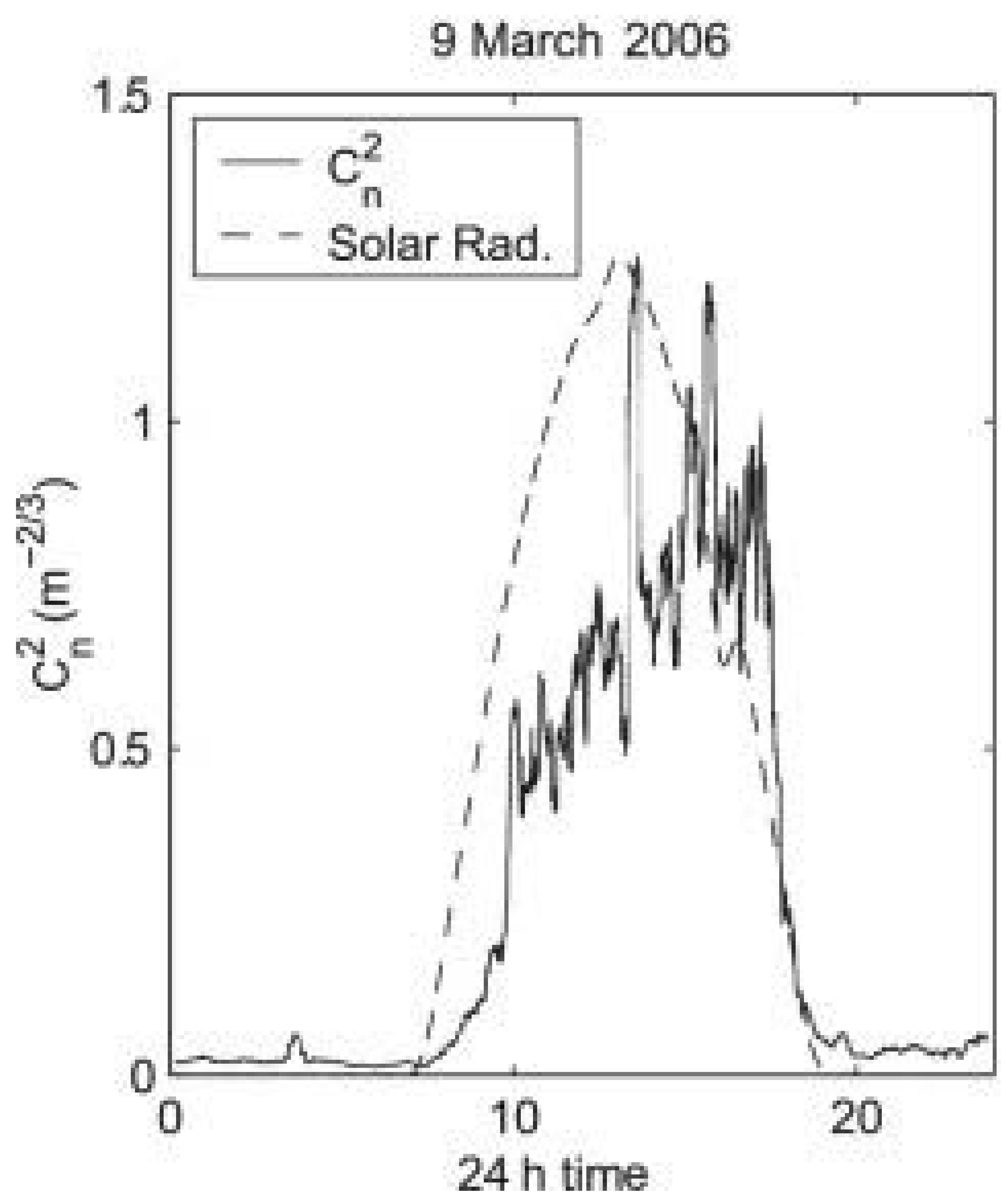


Figure 3: Effect of Solar Insolation on ***C_n^2***

Need of Atmospheric Turbulence Correction?

Atmospheric turbulence imposes limitations on sensors used to record image sequences over long distances. The resultant video sequences appear blurred and waver in a quasi-periodic fashion resulting in a loss of detail in the video sequences. This poses a significant problem in certain fields such as astronomy and defence (long range surveillance).

Characteristics of Atmospheric Turbulence

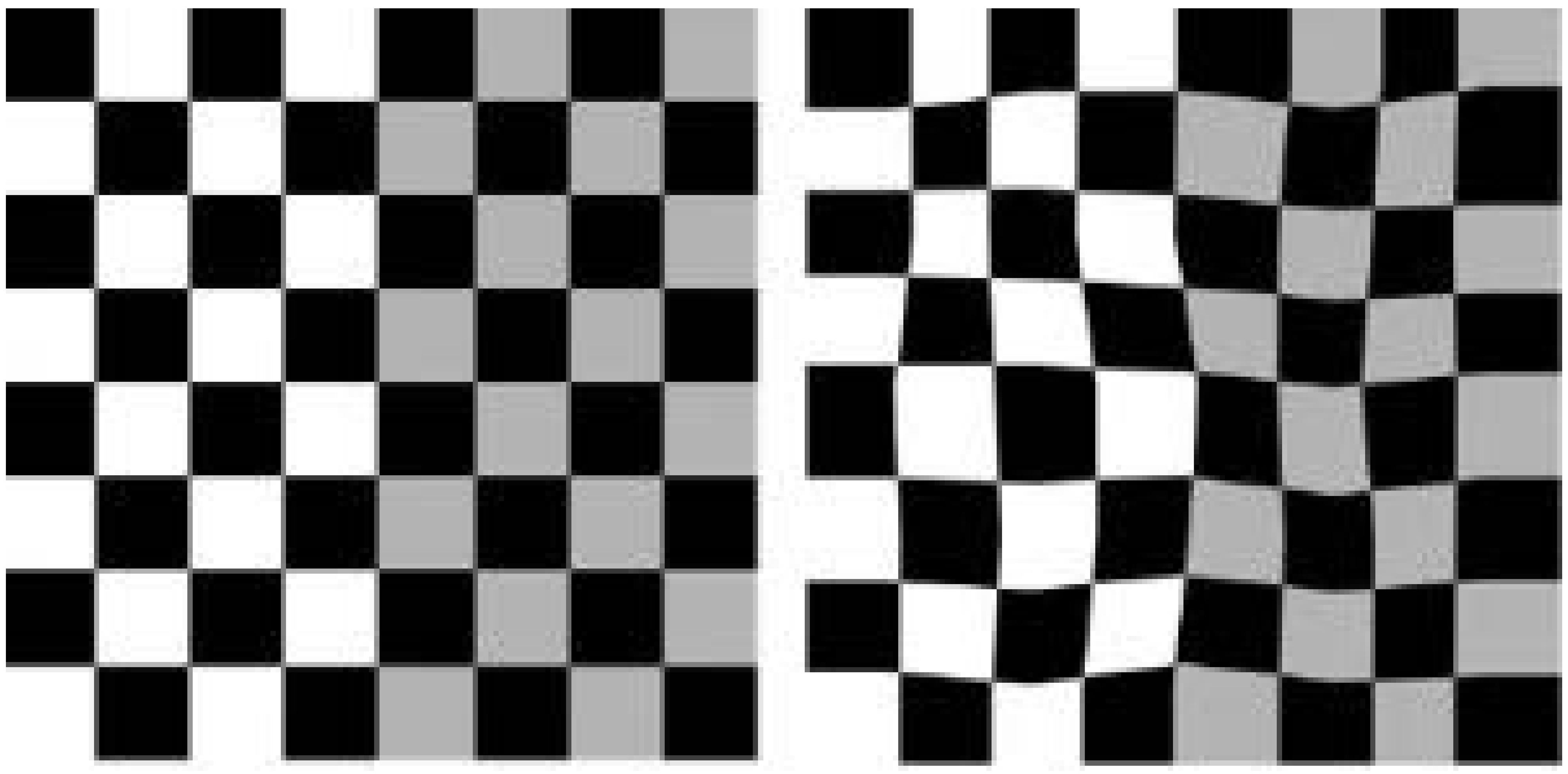
The effects of atmospheric turbulence can be divided into two categories:

- Geometric Distortion
- Blurring

Geometric Distortion

Geometric Distortion causes deformation in the object shape. Shape deformities poses severe challenges in centroid calculation, structural analysis, object recognition etc. and thus adversely affecting the accuracy, reliability and performance of overall system.

Fig. 3 below shows the effect of geometric distortion.



(a) (b)

Figure 3: (a) Check-board Image
(b) Geometric distorted Image

Blurring

Blurring adversely affects the sharpness and contrast of the image. Finer details of the image are lost. Also, sharp and high contrast edges in the scene become gradual transitions.

Geometric Distortion causes deformation in the object shape. Shape deformities poses severe challenges in centroid calculation, structural analysis, object recognition etc. and thus adversely affecting the accuracy, reliability and performance of overall system.

Figure 4 below shows the effect of blurring.

(a) (b)

Figure 4: (a) Original Lenna Image
(b) Blurred Image

Atmospheric Turbulence Degradation Model

Atmospheric turbulence degraded sequence f can be modelled as

$$f_i(x) = D_i(H(u(x))) + \text{noise}$$

Mathematical Model

Where, ***u*** is the static original scene we want to retrieve, ***fi*** is the observed image at time ***i***, ***H*** is a blurring kernel, and ***Di*** is an operator which represents the geometric distortions caused by the turbulence at time ***i***.

Analysis of Existing Methods

A lot of work has already been done in the field of restoring/reconstructing images from atmospheric turbulent degraded image sequence. Here we discussed and compare several of such methods/algorithms.

Time Averaged Algorithm

This technique divides heat scintillation into two separate steps i.e. distortion and blurring. Each step is then dealt with individually. The first step uses some form of image registration to bring the images into alignment and compensate for the shimmering effect. The alignment is usually done against a reference frame. The second step deals with the blurring induced by atmospheric turbulence. This is usually compensated for by making use of a blind de-convolution algorithm or by using image fusion.

Cons: The algorithm has problem in dealing with real motion present in image.

FATR

It stands for First Average Then Register. This algorithm registers each frame in the image sequence against an averaged reference or prototype frame. Registration is performed by cross correlation between two windowed regions. Registered frames are averaged again to obtain a new reference frame and the sequence is put through the algorithm once again.

Cons: The problem in this method is that the blur due to the temporal averaging will still be present and it cannot deal well with real motion present in scene.

FRTAAS

It stands for First Register Then Average And Subtract. The FRTAAS algorithm aims to address the issue present in FATR. In this method, a sharpness metric is used to select the least blurred frame in the sequence. All frames in the sequence are then warped to the reference frame. The shift maps that are used to warp the frames in the sequence to the reference frame are then used to determine the truth image.

Cons: The algorithm has problem in dealing with real motion present in image.

ICA

It stands for Independent Component Analysis. The FRTAAS algorithm aims to address the issue present in FATR. In this method, a sharpness metric is used to select the least blurred frame in the sequence. All frames in the sequence are then warped to the reference frame. The shift maps that are used to warp the frames in the sequence to the reference frame are then used to determine the truth image.

Cons: Algorithm is not capable of removing geometric distortion and the effect of heat shimmer also remained. Also, it has problem in dealing with real motion present in image.

CGI (Control Grid Interpolation)

It is a technique used for performing spatial image transformations. An image is initially segmented into small continuous square regions, the corners of which form control points. These control points are used as anchors in which the intermediate vectors are calculated using bilinear interpolation. CGI allows for the representation of complex motion making it suitable for images distorted by atmospheric turbulence.

Pros: CGI algorithm is capable of reducing geometric distortion whilepreserving real-motion present in the scene.

Comparison

It was shown that all the algorithms were capable of reducing the geometric distortions present in the sequences with the FRTAAS, CGI and Time-averaged algorithms outputting sequences that are stable and geometrically improved.

Turbulence-degraded sequences without motion

Fig. 5 shows that all the algorithms showed a reduction in the geometric distortions. CGI, FRTAAS and the Time-averaged algorithms output a stable sequence with few to no discontinuities. ICA algorithm reduces atmospheric turbulence with the distortions, though present appears to move more slowly.

Time-averaged algorithms performed well followed by CGI, ICA and FRTAAS algorithm.

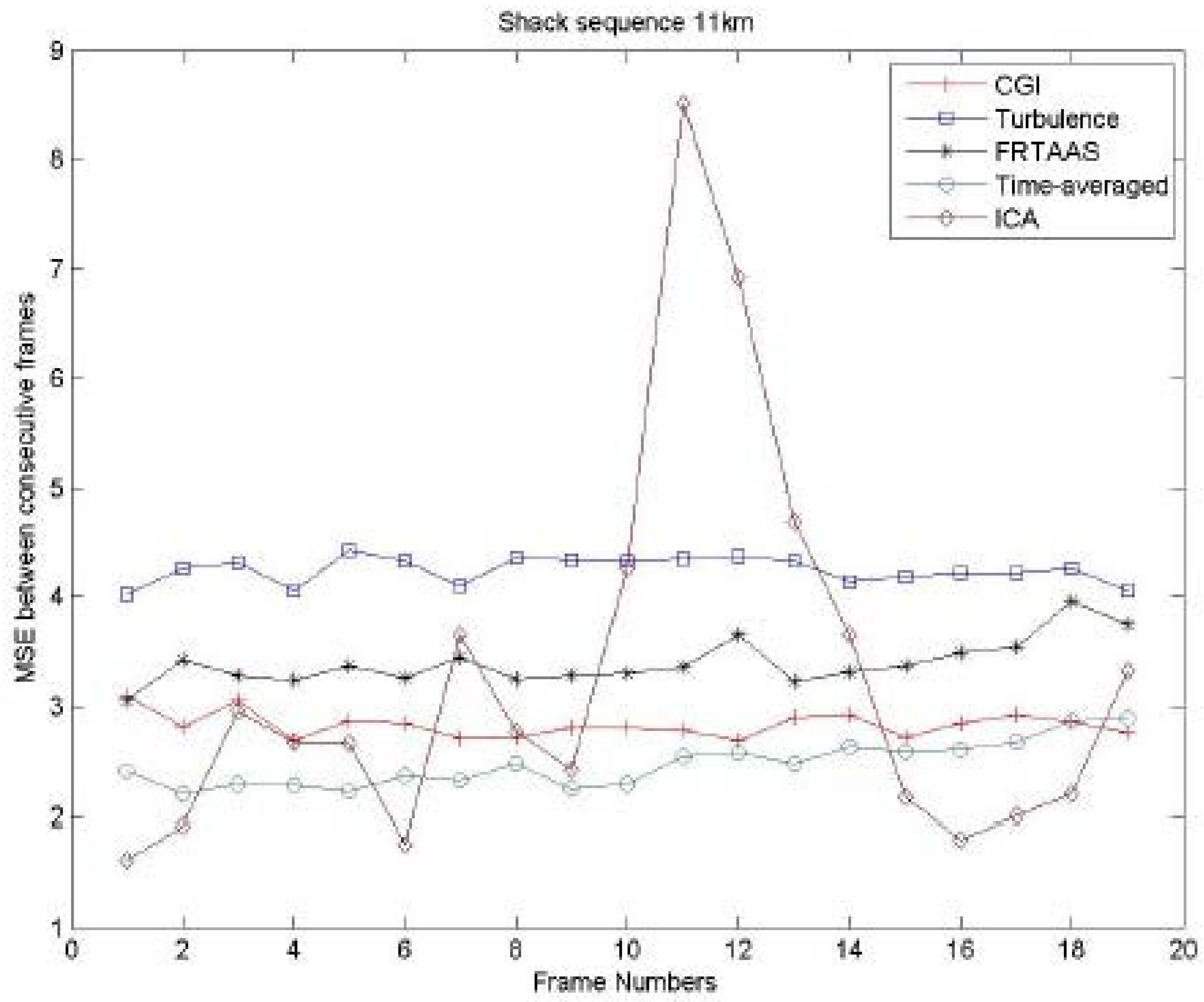


Figure 5

Turbulence-degraded sequences with motion

Fig. 6 shows that FRTAAS and Time-averaged algorithms broke down in the presence of motion. ICA algorithm reduced geometric distortions but the effect of heat shimmer was still present. CGI algorithm showed a stable output sequence with improvements over the turbulence sequence.

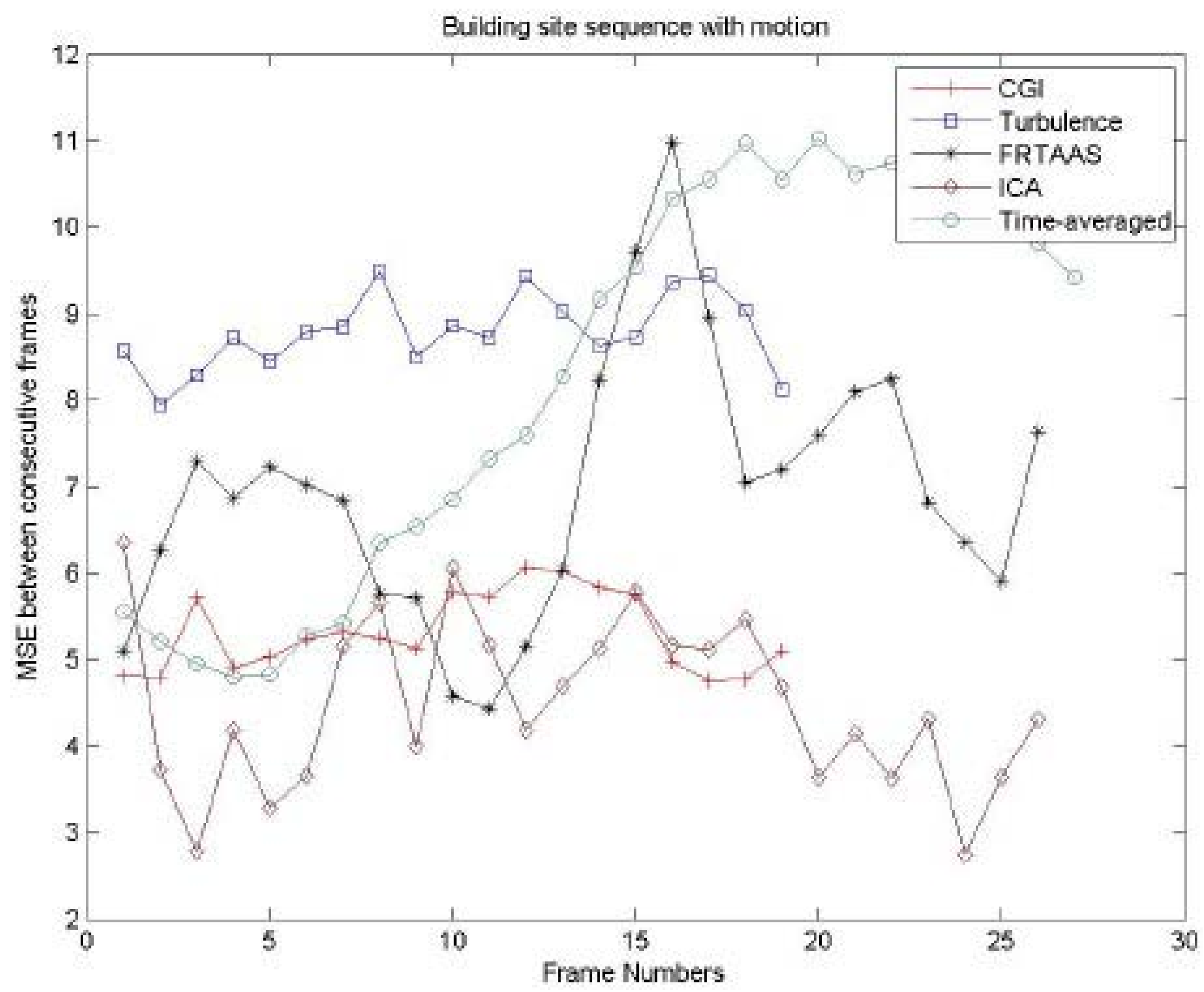


Figure 6

Conclusion

From this analysis it is clear that CGI algorithm has the best overall performance in both scenarios.

Proposed method

Comparison of various algorithms shows that a Time Averaged algorithm is a good option to be considered for Atmospheric Turbulence Correction. Moreover, the simplicity of this method makes it the best candidate in a real-time scenario.

Here we propose a Time Averaged based method for Atmospheric Turbulence Correction. Algorithm deals with atmospheric turbulence in following two steps:

- Geometric Distortion Correction
- Blur Reduction

Assumptions

The nature of atmospheric turbulence is assumed to be quasi-periodic. This means that the net displacement over a period of time is approximately zero.

To illustrate this, a plot of motion of pixels from real-turbulence degraded sequences is shown in Fig. 7 below.

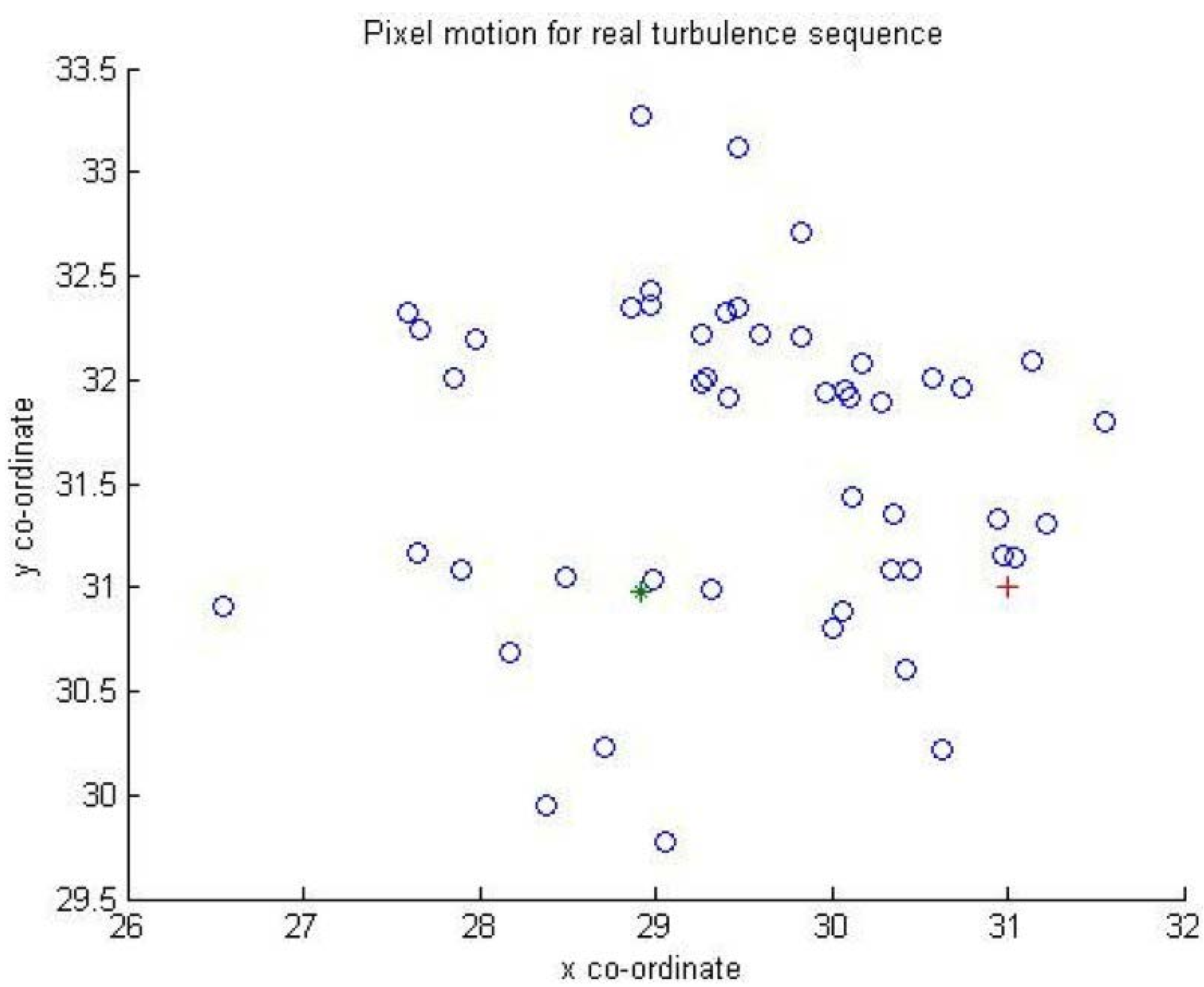


Figure 7: Motion of a pixel in a turbulence sequence

The pixel motion remains within a specified radius showing the quasi-periodic nature of turbulence. The **'+'** shows the location of the pixel in the initial frame. The **'*'** shows the average of the pixel co-ordinates and would correspond to the estimated true location of the pixel in the initial frame.

Step 1: Geometric Distortion Correction

Most of the multi-frame image reconstruction approaches for turbulence mitigation utilize the reference image for image registration. Reference image can be estimated simply by averaging all the observed frames in the image sequence. We use cumulative temporal averaging technique.

$$\mathrm{Re}\,f_{i+1} = \frac{F_{i+1} + \mathrm{Re}\,f_i}{i+1}$$

Where, F, Ref and i are the target image, reference image and index of an image respectively. Reference image is incrementally updated as the new frames in sequence are processed.

By cumulative averaging the turbulent frames, the geometric distortion which is quasi-periodic in gets cancelled out thus giving a distortion free resultant frame. This process is depicted in Fig. 8 below.

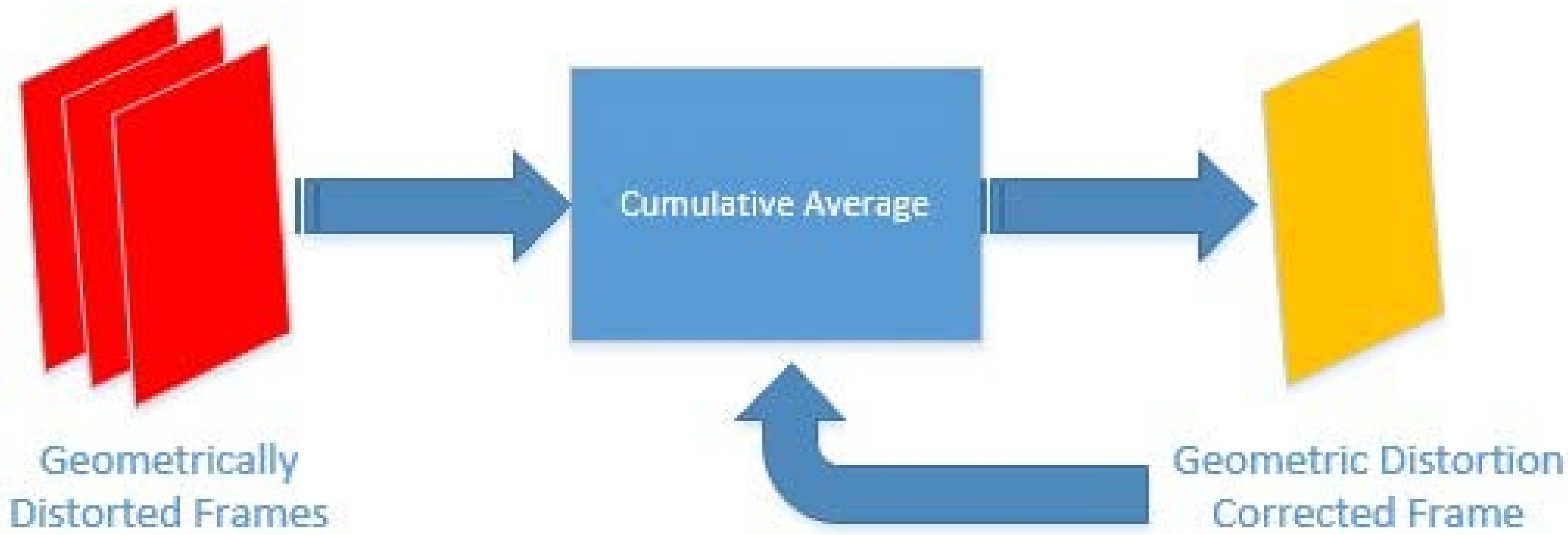


Figure 8: Geometric Distortion Correction by Cumulative Averaging method

To have a better control over how fast the reference or resultant frame adapts to changes, we introduce a weight parameter α .

$$\mathrm{Re}\,f_{i+1} = \frac{\alpha\, F_{i+1} + (1-\alpha)\mathrm{Re}\,f_i}{i+1}$$

That is, α regulates the update speed of reference frame. A high α value will cause reference frame to update fast resulting in lesser degree of geometric distortion correction and lesser motion blur. While, a lower value will cause reference frame to update slowly resulting in higher degree of geometric distortion correction but more motion blur.

Algorithm Steps:

1. Take the turbulent image withgeometrical distortion.
2. Apply weight to new image and previous averaged image (if present).
3. Calculate cumulative average.
4. The updated averaged image is the distortion corrected image.
5. Repeat steps 1 and 2.

Step 2: Blur Reduction

Blur reduction in distortion corrected image is done by Laplacian Sharpening.

The Laplacian operator is a second order or second derivative method particularly good at finding the fine detail in an image. Any feature with a sharp discontinuity, like edges will be enhanced by a Laplacian operator. In other words, the Laplacian of an image highlights regions of rapid intensity change and is therefore useful in edge detection.

The Laplacian L(x,y) of an image with pixel intensity values I(x,y) is given by:

$$L(x,y) = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}$$

This can be calculated using a convolution filter. Since the input image is represented as a set of discrete pixels, we have to find a discrete convolution kernel that can approximate the second derivatives in the definition of the Laplacian. Two commonly used small kernels are shown in Figure 9 below.

0	−1	0
−1	4	−1
0	−1	0

−1	−1	−1
−1	8	−1
−1	−1	−1

Figure 9: Laplacian Kernels

Note: We have defined the Laplacian using a negative peak because this is more common; however, it is equally valid to use the opposite sign convention.

Using one of these kernels, the Laplacian can be applied to an image using standard convolution methods.

With fig. 8 kernels, if we add the original image to filtered image the edges get enhanced thus increasing the sharpness of the image. In case if using +ve peak kernels, we need to add both the images to get the sharpened image.

Fig. 10 below depicts the process.

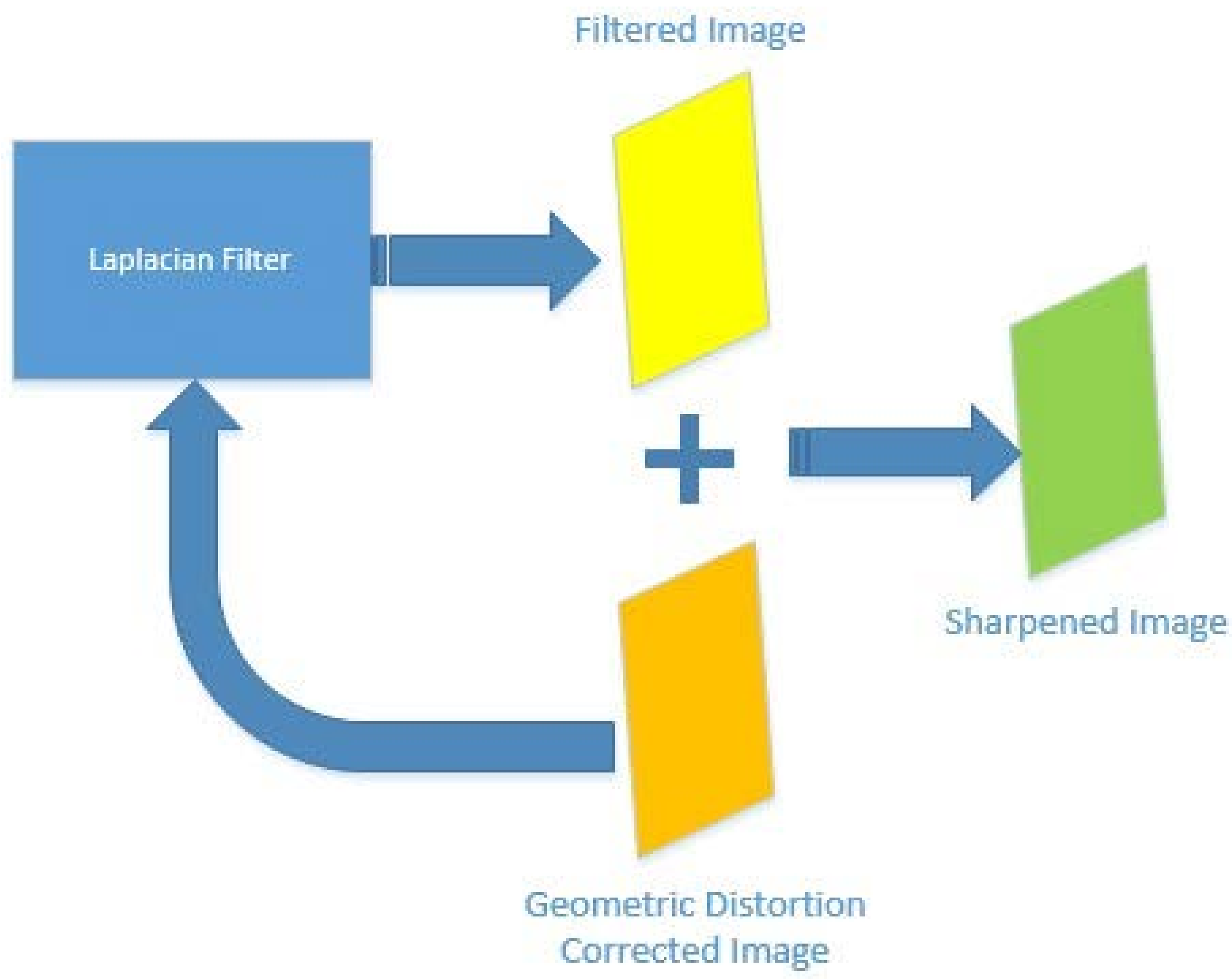


Figure 10: Blur reduction by Laplacian Sharpening method

Algorithm Steps:

1. Take a −ve or +ve peak laplacian kernel.
2. Perform 2-D convolution on geometric distortion corrected image with the laplacian kernel.
3. With −ve peak kernel, add the filtered image to geometric distortion corrected image. With +ve peak kernel, subtract the geometric distortion corrected image from filtered image.
4. The resulting image is the sharpened image.

Results

Test Environment

The proposed algorithm was implemented in C++ using OpenCV library. Table 1 below gives the test environment setup on which the algorithm was tested.

PC Specification	
CPU	Core i7 Dual Core@ 2 GHz
RAM	16GB
OS	Win8
Software Environment	
Language	C++
Library	OpenCV 2.4.10
UI	QT 5.3
Compiler	MSVC2010

Table 1: Test Environment Specs

Test Results

Table 2 below gives the test results of the algorithm.

Test Result	
Input Image Resolution	640x480
Avg. Time/frame	22 msec.

Table 2: Test Environment Specs

Fig. 11, 12, 13 and 14 below show sample results.

(a) Turbulent Image (b) Geometric Distortion Correction (c) Blur Correction

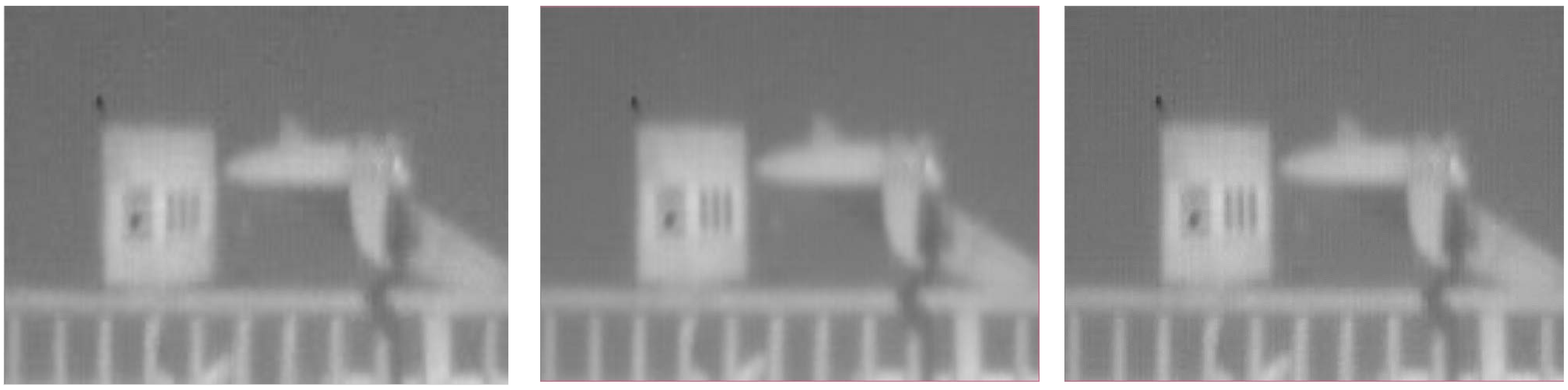
Figure 11: Dataset-1

(a) Turbulent Image (b) Geometric Distortion Correction (c) Blur Correction

Figure 12: Dataset-2: Sirius

(a) Turbulent Image (b) Geometric Distortion Correction (c) Blur Correction

Figure 13: Dataset-3: Moon



(a) Turbulent Image

(b) Geometric Distortion Correction

(c) Blur Correction

Figure 14: Dataset-4

Limitations & Applications

The proposed algorithm cannot handle real motion in the scene very well.

This algorithm is well suited for imagery which has no or very slow real motion.

Algorithm works well in tracking targets in narrow field of view. It can be used for long range structural analysis and long range fixed view surveillance.

Going Ahead

Remove Motion Blur

It is observed that the given algorithm is not able to handle real-motion which may be present in real video sequences thus resulting in motion blur.

GPU or FPGA Implementation

Though the algorithm is able to achieve real-time performance at 640x480 resolution, for higher resolution the performance is sure to get adversely affected. So, a GPU accelerated or FPGA implementation can be developed.

Improving Blur Reduction

The Laplacian kernels specified here are approximating a second derivative measurement on the image, hence they are very sensitive to noise. To counter this, it is suggested to use a noise reduction filter as a pre-processing step. This pre-processing step reduces the high frequency noise components prior to the differentiation step.

It is recommended to perform Gaussian Smoothing before applying Laplacian filter. In fact, Laplacian of Gaussian kernel can be constructed to perform both operations in a single convolution step.

Conclusion

The algorithm proposed in this paper is effective in correcting distortion and blur effects of atmospheric turbulence. Also, it is able give real-time performance with resolution of 640x480 at 30 FPS.

Although, this algorithm is not able to handle real motion if present in the scene, still it is effective in narrow-view object tracking, structural analysis and object recognition of static objects.

About the Company

Founded in 2009, Logic Fruit Technologies has a highly experienced management team, which is backed by a talented and committed engineering team. Almost all the employees are hand-picked from IITs and NITs.

The company is leading its way into the next generation High Speed Serial Protocols (3 Gbps and above) like PCIe, Fibre Channel, USB, 3G-4G wireless protocols, HDMI and so on. The company has worked closely with reputed high tech companies like Agilent Technologies.

The company has gained a high reputation in market in such a short span due to its innovative outsourcing model, uncompromised quality of work and deep domain knowledge. The main goal of the company is to minimize client's overhead and it works on the simple motto "Outsource and Forget". It has a track record of always exceeding the client's expectations.

For further information, check the website
www.logic-fruit.com

Thank You!

Does anyone have any questions?

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