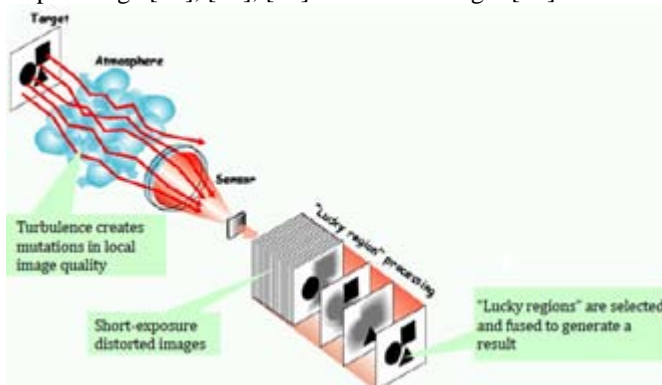






for imaging systems to restore a single high quality image from the observed sequence or videos can be divided in to two main categories. One category is based on *multi-frame reconstruction algorithms* [6], [12]. These algorithms first requires a non rigid image registration method to register each observed frame with respect to a turbulence free grid and use the registration parameters to estimate the corresponding deformation matrix  $F_k$  [27]. Then a sharp image is reconstructed through a Bayesian reconstruction method. The main problem for multi- frame reconstruction algorithms is that in general they hardly estimate the actual point spread function (PSF), which is spatially and temporally changing.

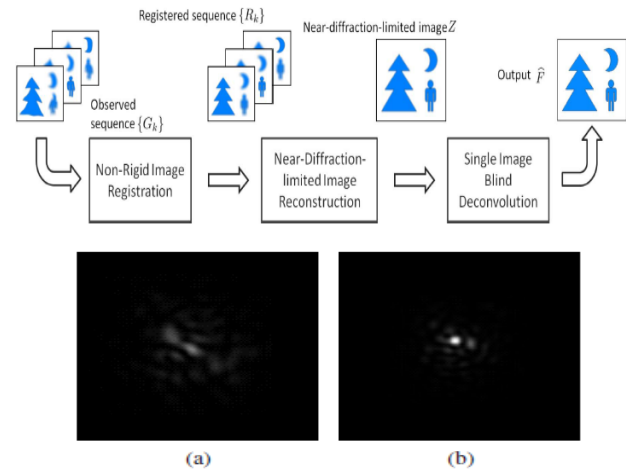
Another class of approaches called *lucky imaging* includes lucky framing and fusion algorithms to reduce the blurring affects [7], [11], [28], [29]. The image selection technique used to find lucky frames (frames of best quality) and output image is produced by fusing these lucky frames [28], [29] hence named as lucky imaging. The problem of this approach is the very low probability of existence of a whole high- quality frame. It is favored for *isoplanatic* scenarios- a small angle that can be viewed as containing space-invariant blur [7]. For *anisoplanatic* scenarios *Vorontsov et al.* [30] proposed “lucky region” restoration algorithm where it is shown that for short-exposure images turbulence creates “mutations” in the local image quality and randomly makes some regions sharper, which are called lucky regions. Theses lucky regions then fused to produce a high quality output image [30], [31], [32] as shown in Fig 3 [30].



**Figure 3:** Lucky-region fusion approach [30]

A difficulty with this method is again the low probability of the appearance of lucky regions. Although high-quality regions happen more frequently than high-quality frames, this method generally requires a large number (usually hundreds) of frames to create one single sharp image. Another problem is that this method is applicable only for short-exposure videos, while for long-exposure videos motion blur makes the lucky regions too rare to be useful. Even though turbulence caused blur is strongly alleviated through the fusion process, the output still suffers from the blur caused by the diffraction-limited PSF as shown in fig 5. In [27], [33] *Xiang Zhu* and *Peyman Milanfar* proposed a new approach: *Removing atmospheric turbulence via space-invariant deconvolution* to correct geometric distortion and reduce space- and time- varying blur capable of restoring a single high-quality image from a given image sequence distorted by turbulence. This new framework is proposed for restoring a single image in anisoplanatic scenarios. The 3-D physical scene is assumed to be static, while the air between

the scene and sensor is affected by atmospheric turbulence. This approach is designed to reduce the space and time-variant deblurring problem to a shift invariant one. It focuses on the observed regions convolved by near-diffraction-limited PSFs, which can be viewed as space and time-invariant. Fig -4 is the block diagram of their proposed approach [33]. Experiments show that this frame-work is capable of alleviating both geometric deformation and blur, and significantly improving the visual quality.



**Figure 4-** Block diagram: Removing atmospheric turbulence by space-invariant deconvolution [33], Fig 5-PSF examples:

(a) an example of PSF caused by air turbulence; (b) an example of near-diffraction-limited PSF [27]

Review of Some real video data tested to illustrate the performance of the [27], [33] proposed restoration framework by *Xiang Zhu* and *Peyman Milanfar* shown. The existing restoration algorithm of multi-frame reconstruction approach [12] and lucky imaging [30] tested data are also shown as comparison. The first set of images ( $410 \times 380 \times 80$ ) show the Moon surface imaged from a ground based telescope (see Fig 6[27] (a)). From (b) we can see that though the output image of lucky imaging looks slightly sharper than one of the observed frames, it is still quite blurry probably due to the diffraction-limit blur and the limited number of frames. Multi-frame reconstruction algorithm provides a better result but with some details (small craters) vanished (Fig. 6 (c)). The approach [33] gives a significant improvement in visual quality (Fig. 6(d)). It successfully removed blur and meanwhile recovered many small craters on the surface that can hardly be seen from either original frame or the outputs of other two methods.

The term adaptive optics-AO refers to an optical system that correct aberration introduced along the propagation path in atmosphere of imaging system. The main purpose of this pre-processed or hardware based technique- AO is to physically compensate for distortion of air turbulence, thereby improving image quality. A typical AO system (as shown in fig 7[36]) is a combination of a wave-front sensor that measures the aberrations; a control system that reads the wave-front sensor and calculates and applies correction and a corrective element that physically change the impinging light in order to remove aberrations caused by distorted wave-front.

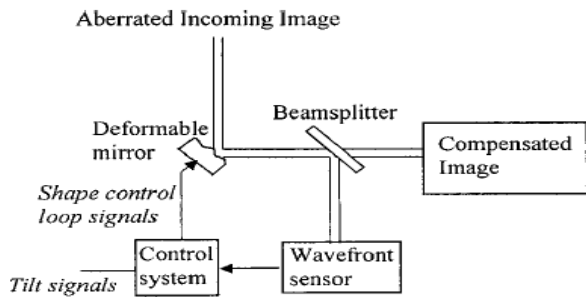


Figure 7: AO imaging system [36]

#### Alternative: Adaptive Optics

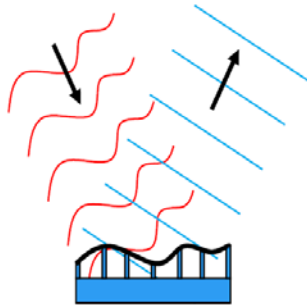


Figure 8: correcting element –DM [30]

The most common type of correcting element in adaptive optics is deformable mirror (DM) i.e. a flexible mirror with actuators, usually piezo-electric, that can deform the surface of the mirror to the phase conjugate of the aberrated wavefront, removing or greatly reducing the aberration in the reflected light as shown in fig 8 [30].

Such system while very successful in the past decades, have also proven extremely bulky, costly and complex to operate. The use of MEMS technology in optics termed as micro-opto-electro-mechanical systems-MOEMS and the DM of MOEMS technology in AO results a reduction of cost, complexity and weight. A standard AO system requires large optical benches, several racks of dedicated power supplies and computer equipment. By the use of MOEMS devices all the full functioning AO system can fit in to a single enclosure and made AO portable.

#### 4. Discussion

In this literature survey we discuss the turbulence; its nature, causes and impacts on optical transmission path of long distance imaging systems with turbulence theory "Kolmogorov". The discussed impacts of atmospheric turbulence, geometric deformation and time-/space- varying blur can be reduced by three different approaches each of which has performance based and software/hardware based limitations. Like software based approach is of low cost which we discussed with restoration algorithms: multi-frame reconstruction, lucky-imaging along their shortcomings and "Removing atmospheric turbulence via space-invariant deconvolution" [33] which is recent one restoration algorithm is discussed with review of their experimental data. A pre-processing approach of MEMS based AO is also a part of this literature survey. In the end, we conclude that a

hybrid approach of pre-processing and post-processing may effectively reduce the impact of air turbulence on imaging.

#### 5. Future Scope

We can implement the best algorithm after pre-processing approach of MEMS-DM based AO to reduce deformation and blur caused by atmospheric turbulence (non-stationary random fluctuations in refractive index of air), recovering details of scene and significantly improve the visual quality. By the use of hybrid technique fidelity of long distance ground/space based imaging may improved. Also such approach can be implementing to remove other environmental degradations.

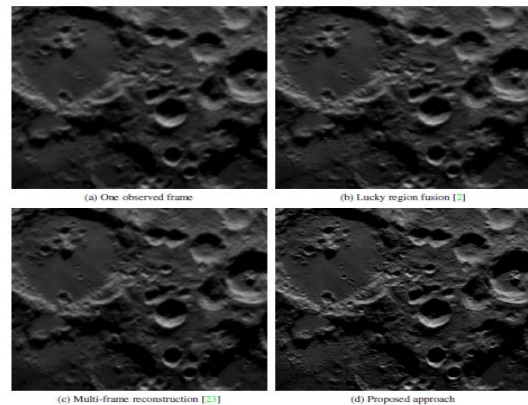


Figure 6: Image reconstruction result using 80 frames taken from the video *Moon Surface* distorted by real atmospheric turbulence [27]

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