Dynamic aperture diversity

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ABSTRACT

Recent research has shown that imaging through atmospheric turbulence with 3-meter class telescope apertures is improved by partitioning the aperture into annuli. Here we show some preliminary results that suggest there is an optimal configuration for the partitioning that depends on the strength of the atmospheric turbulence conditions. This configuration can be predicted by maximizing the overall speckle transfer function for the multi-aperture system. These results suggest the use of dynamic aperture partitioning to provide a way to ensure the best data set is acquired for any given turbulence condition. Such dynamic partitioning could be achieved using a digital micro-mirror device (DMD).

1. BACKGROUND

Our recent research has shown that imaging through atmospheric turbulence with a 3-meter class telescope is improved by partitioning the aperture into annuli [1]. This partitioning provides diversity in the aperture sizes while still capturing all the photons incident on the full aperture. The advantage of doing this is that the different aperture sizes provide data sets with different resolutions: an important lever in the image restoration process, especially for data acquired through strong atmospheric turbulence [1]. The performance increase obtained by using an aperture diversity approach to imaging over the conventional approach of collecting data with the full telescope aperture and then restoring the data, is highlighted in Fig.1. This improved capability allows us to image through higher levels of turbulence than was previously possible and opens the door for imaging both during daylight hours and at low elevation angles. As such, it provides a significant step towards the goal of uninterrupted, full sky, monitoring for space situational awareness.

Our initial studies of aperture diversity were performed for a single set of aperture sizes. This was because we originally envisioned a multi-telescope application of the technique to the current suite of telescopes atop Mount Haleakala. This is an unnecessary restriction.

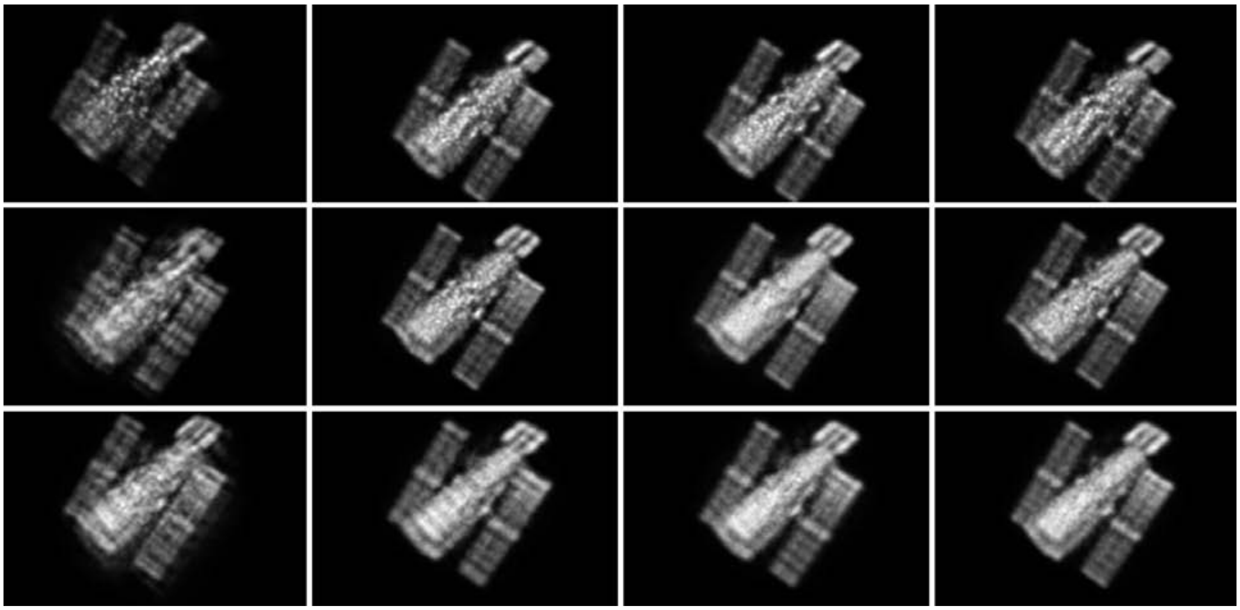
Here we extend our original aperture diversity studies and show that the sizes of the annular sub-apertures should change as observing conditions change.

2. DEPENDENCE OF APERTURE CONFIGURATION ON TURBULENCE

The speckle transfer function (STF) shows the effect of the Earth's atmospheric turbulence on the modulation transfer function for the imaging system. Here we use the variation of the STF with spatial frequency as a measure of the information passed by the imaging system for the given turbulence conditions (measured by D/r_0 where D is the diameter of the aperture and r_0 is the spatial coherence length of the atmosphere). We compute the STF by summing the power spectra of 500 realizations of a point source imaged through the turbulence (Fig. 2).
We then define the optimal set of annuli for a given set of turbulence conditions to be the annuli that maximize the value of the integral of the STF over all spatial frequencies (see Fig. 3). This is analogous to the practice of maximizing the area under an optical system's MTF to provide the best image quality [2].

A

B



C

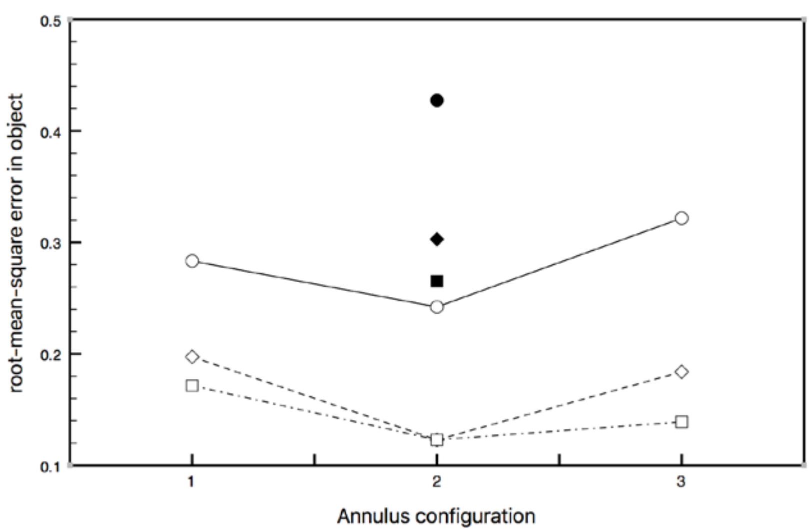


Fig.1. (A) These images depict the apertures used to generate the data for the restorations in the columns in (B) directly below. (B) First column is restoration of single 3.6m aperture data acquired through turbulence with a spatial coherence length, r_0=12cm (i.e. D/r_0=30). The next three columns, left to right: The restorations obtained using (configuration 1: r_1=0.3, r_2=0.7), (configuration 2: r_1=0.5, r_2=0.8), and (configuration 3: r_1=0.7, r_2=1.0) with identical atmospheric turbulence. All restorations have been convolved with a Gaussian with σ=1 pixel. Top to bottom: Results for three separate data sets. The improvement in image fidelity by using multi-aperture diversity is clear. (C) This plot shows the root-mean-square error in the restored images for the single full aperture data (isolated points) and the aperture diverse data for the different aperture configurations (points joined by lines).

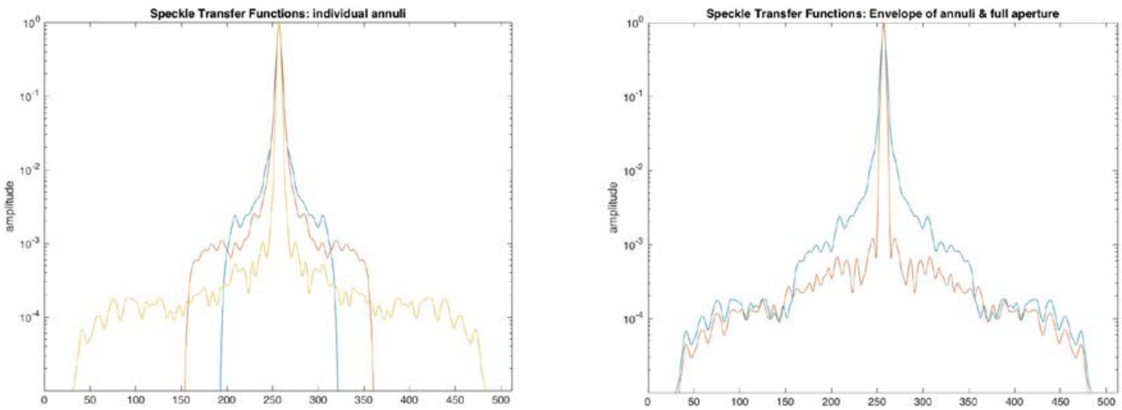


Fig. 2. These plots show the speckle transfer functions (STFs) for observations made at $D/r_0=30$ with a 3.6m aperture with a 0.4m secondary mirror obscuration. Left: the individual STFs for three annuli with inner and outer diameters of 0.4m & 1.0m (blue), 1.0m & 1.6m (orange), and 1.6m & 3.6 m (yellow). Right: The envelope of the maximum values of the STFs for the 3 annuli (blue) along with the STF for the full aperture (orange).

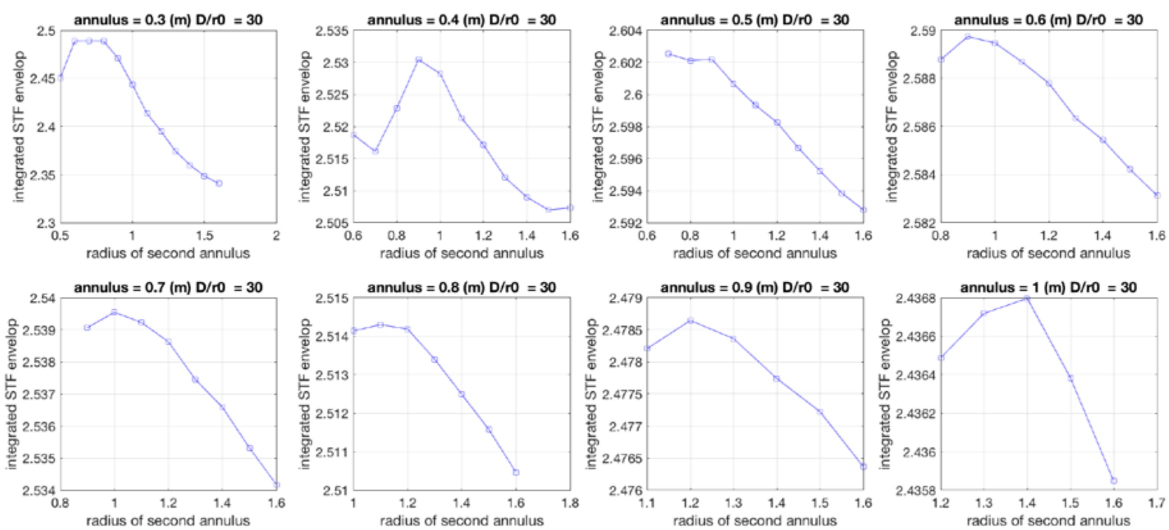


Fig.3. These plots show how the integrated STF value varies with the outer radius of the middle annulus for a given outer radius of the inner annulus (given at top of each plot) for observations acquired through $D/r_0=30$.

3. CONCLUSIONS

We have found that there appears to be an optimal configuration for the partitioning of the aperture that depends on the strength of the atmospheric turbulence conditions. This configuration can be predicted by maximizing the overall speckle transfer function for the multi-aperture system. If verified, these results suggest the use of dynamic aperture partitioning should provide a way to ensure the best data set is acquired for any given turbulence condition. Such dynamic partitioning could be achieved using a digital micro-mirror device (DMD).

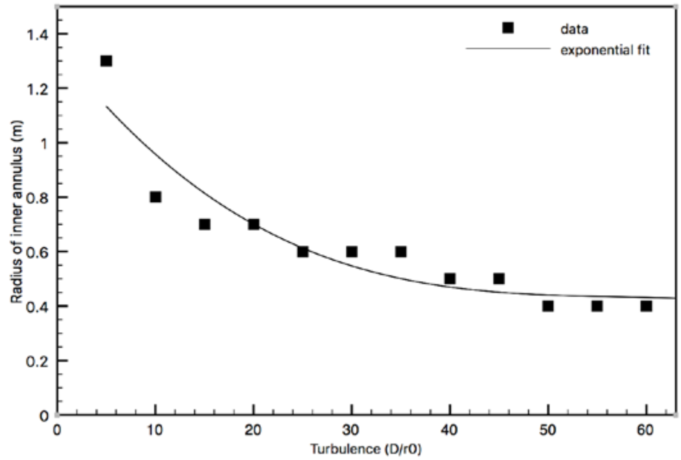


Fig.4. This figure shows the variation of the predicted optimal radius of the inner annulus, based on a speckle transfer function analysis, for a two annular-aperture imaging system, for different levels of atmospheric turbulence.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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2 Boreman, G. D., Modulation transfer function in optical and electro-optical systems, Tutorial Texts in Optical Engineering, Volume TT53, SPIE Press, 2001.