

Image selection by using an on-line fast shutter driven by Tip-Tilt signal

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ABSTRACT

The possibility of improving the image quality of the Italian Telescopio Nazionale Galileo (TNG) by means of real-time on-line image selection by using a fast shutter is studied. The Tip-Tilt signal is checked against a user defined threshold to trigger on rejection of those images which would significantly degrade the long-exposure point spread function because of jitter broadening.

The dependency of the achievable improvements on the rejection threshold, on the shutter opening and closing times, and on the atmosphere conditions (r_0) is analysed. The pros and cons of a ferroelectric liquid crystal shutter are discussed.

Keywords: adaptive optics, Tip-Tilt, image selection

1 INTRODUCTION

The Adaptive Optics Module (AdOpt) of the "Telescopio Nazionale Galileo (TNG)" will be equipped with a fast shutter for on line image selection. The main purpose of the fast shutter is to select only those "lucky short-

exposure images”¹ which are characterized by good sharpness (see Ref. 2 for examples of sharpness functions). The main idea is to use a sharpness merit function derived from the information given by the AdOpt TNG wavefront sensor. Unfortunately, in the first year of operation only a Tip-Tilt sensor will be implemented in AdOpt³. In this paper by means of numerical simulations we investigate the pros and cons of using the fast shutter driven by such a sensor as an alternative and a back-up option for reducing jitter image broadening.

2 SIMULATION PROCEDURE

The simulation procedure is performed by means of several IDL procedures which, starting from a sequence of arrival angles corresponding to the centroid positions measured by the Tip-Tilt sensor, mimic the opening and closing of the shutter and compute the long exposure Modular Transfer Function (MTF) and Point Spread Function (PSF). The sequence of 16,384 angles of arrival was computed by two of the authors (R.R and E.M) by assuming atmosphere conditions as expected at the TNG site and two different values of r_0 , namely 0.1 and 0.2 m at 700 nm. This sequence, which corresponds to 16.384 seconds sampled at 1 msec steps, was then expanded by a factor 64 in order to mimic a much longer exposure time and to reduce the importance of statistical fluctuations in the results.

We mimic 6 different fast shutters characterized by different speeds. Actually we assign to each one its minimum opening, closing and delay time (namely 1, 10, 20, 30, 50, 100 ms). As a threshold for selecting “good” images we chose 30, 50 and 100 % of the RMS of the arrival angles.

The importance of the shutter speed can be easily understand by looking at Fig. 1.

The problem of non complete acquisition of “good” images during the shutter opening time and of partial/total acquisition of “bad” images during the closing/delay time is much more evident in the lower panel (30 msec shutter speed) than in the upper one (1 ms). This problem causes different degradations of the long exposure MTF as can be seen in Figures 2 and 3 where the effect of the different selection threshold is also shown.

Starting from this degradation function we computed the total long exposure MTFs, assuming four different effective working wavelengths (550, 700, 1250, and 2200 nm, as indicative of V, R, J, and K filters respectively), by multiplying the TNG MTF times the atmosphere short exposure MTF degradation⁴ by the degradation factors given in Figures 2 and 3. Figures 4 and 5 show the so-obtained MTFs for the 30 % threshold and two shutter speeds, namely 1 and 30 msec. As a reference, we also plotted the MTFs corresponding to the short exposure images (no jitter degradation) and to the long exposure image (without any shutter selection). It is evident that using the fastest shutter causes a total MTF which is almost coincident with the one obtained assuming no Tip-Tilt degradation. The two shutter speeds are representative of the best achievable cases if using a ferroelectric liquid crystall shutter or an electronic one, namely 1 and 30 msec respectively. In the first case the delay time of 1 msec is due to the integration time of the Tip-Tilt sensor, since the ferroelectric liquid crystal shutter can be activated in few μ sec. In the second case faster electronic shutters can be obtained only by accepting to use small diameter devices thus reducing significantly the TNG field of view which presently is 2 arcmin in diameter.

Figures 6a and 7a show the PSFs corresponding to the MTFs given in Figures 4 and 5 at 700 nm. The PSFs are scaled to take into account the effective percentage of the total (nominal) exposure time corresponding to the weighted sum of all intervals in which the shutter was totally or partially open. Panels b and c show the PSFs obtainable by increasing the nominal exposure times in order to get the same total flux as in the nominal case (b) or the same central peak (c). The good results obtainable with the 1 msec shutter can be seen, as in

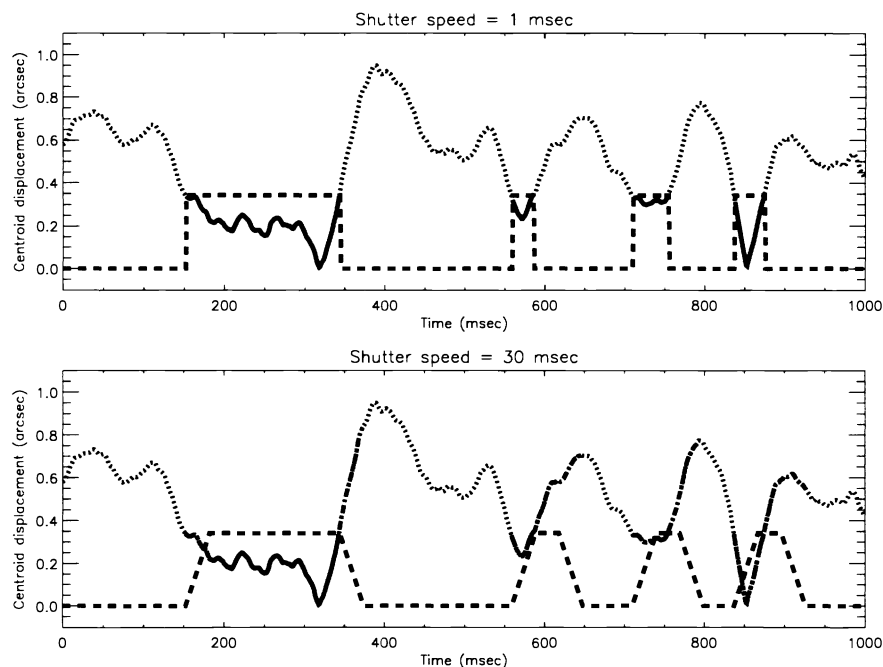


Figure 1: Comparison of different shutter speeds

Figures 4 and 5, by the almost total coincidence of the corresponding PSFs with those obtained assuming no Tip-Tilt degradation (Figures 6b,c and 7b,c). The increase of the exposure time required to move from the PSFs shown in Figs. 6a,7a to those in Figs. 6b,7b and 6c,7c are shown in Figs. 8 and 9 versus the shutter speed for the three different selection thresholds. The values computed for the 1 msec cases include also a factor 2 for giving an estimate of the loss of throughput in the case of a ferroelectric liquid crystal shutter.

3 CONCLUSION

The results obtained in Sec. 2 show that a fast shutter can be used to reduce jitter broadening in long exposure images by selecting “good” images according to the error signal of a Tip-Tilt sensor. By using a very fast shutter, i.e. a ferroelectric liquid crystal one, and an appropriate threshold, it is possible to achieve results comparable to those of a steering mirror Tip-Tilt loop, while intermediate results are achieved with more relaxed threshold and/or shutter speeds. Obviously the main advantages of using a fast shutter method (i.e. lower costs, easier implementation and maintenance, etc.) must be paid by a significant increase in the nominal exposure time to obtain comparable effective exposure times and signal-to-noise ratios. In conclusion, it was shown that a fast shutter in the optical path of AdOpt TNG can be used as a back-up solution for any failure or malfunctioning of the Tip-Tilt loop, even if the main reason for installing the shutter is to apply on line image sharpening driven

by the forth-coming TNG wavefront sensor.

4 ACKNOWLEDGMENTS

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5 REFERENCES

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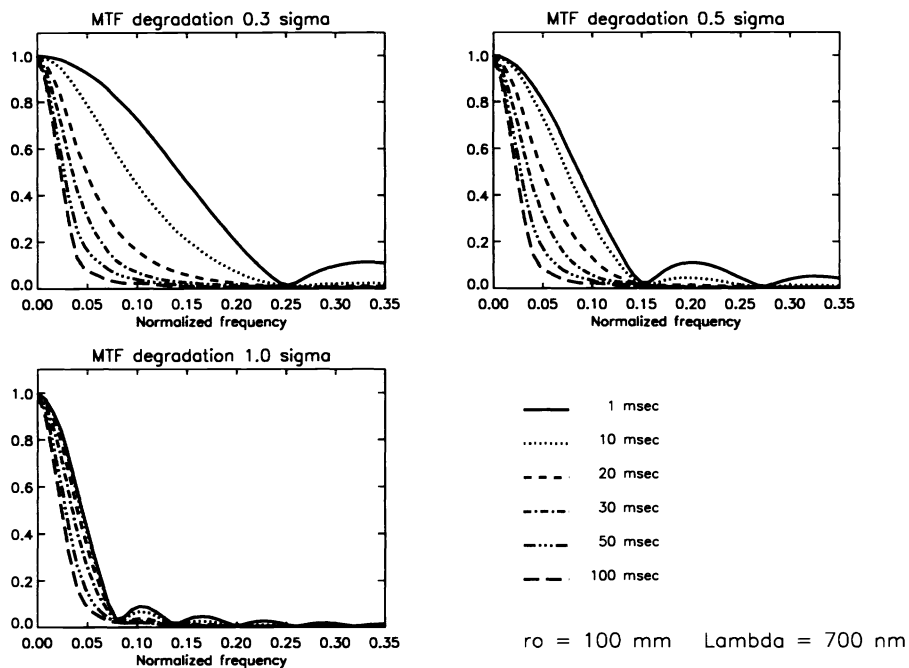


Figure 2: MTF degradation factors due to residual jitter after applying different speed fast shutters

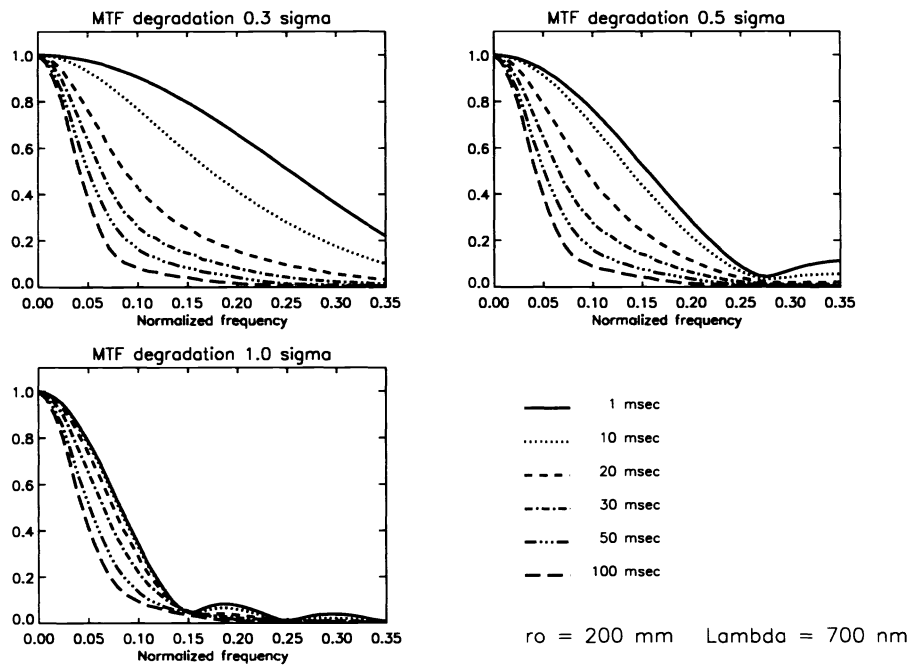


Figure 3: MTF degradation factors due to residual jitter after applying different speed fast shutters

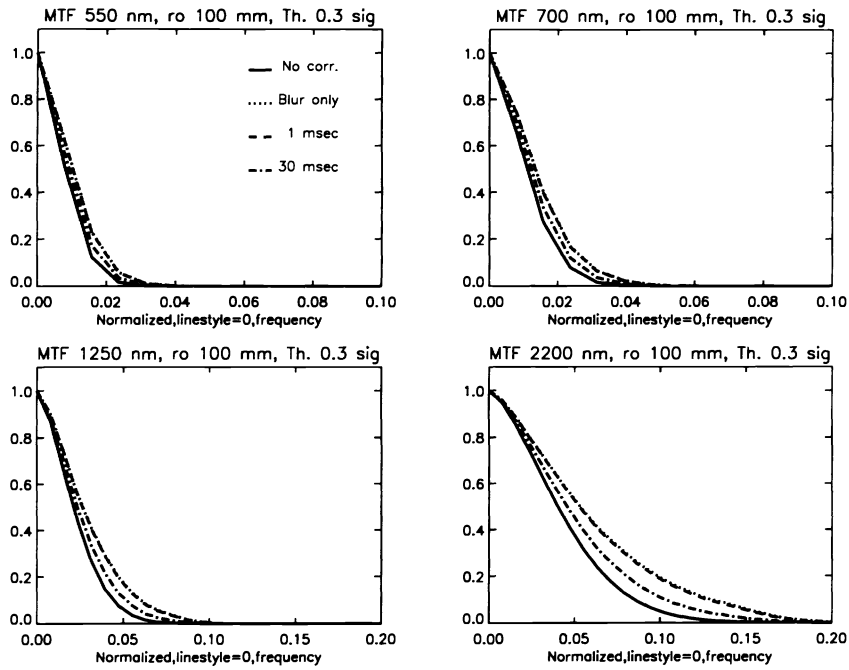


Figure 4: Total MTFs including diffraction, atmosphere blur and residual jitter

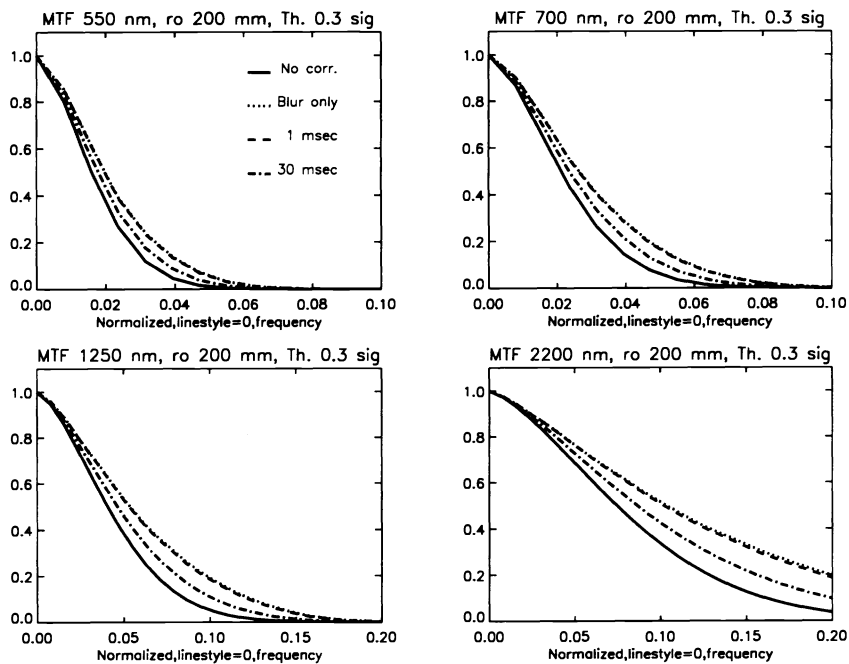


Figure 5: Total MTFs including diffraction, atmosphere blur and residual jitter

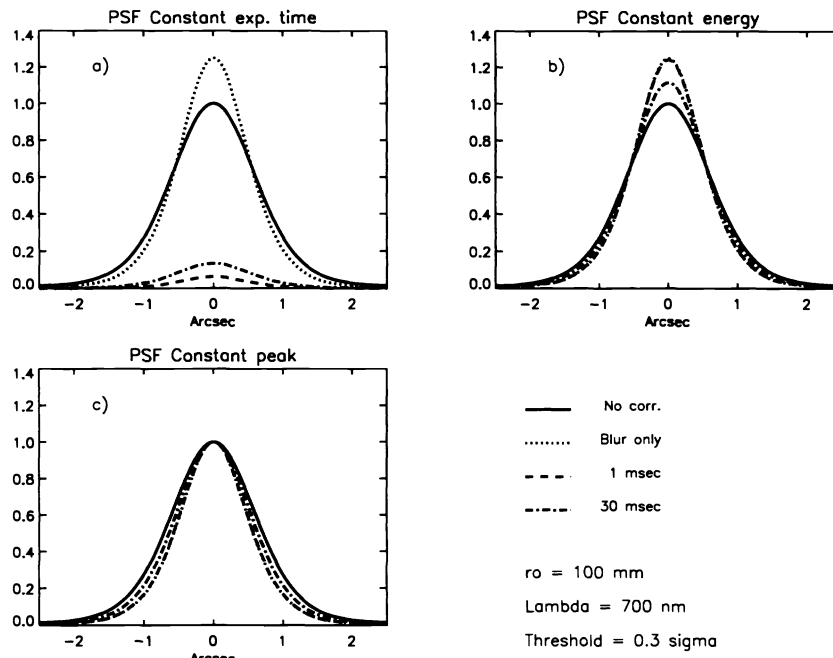


Figure 6: PSFs for images obtained with no-selection, no-Jitter and two different fast shutters

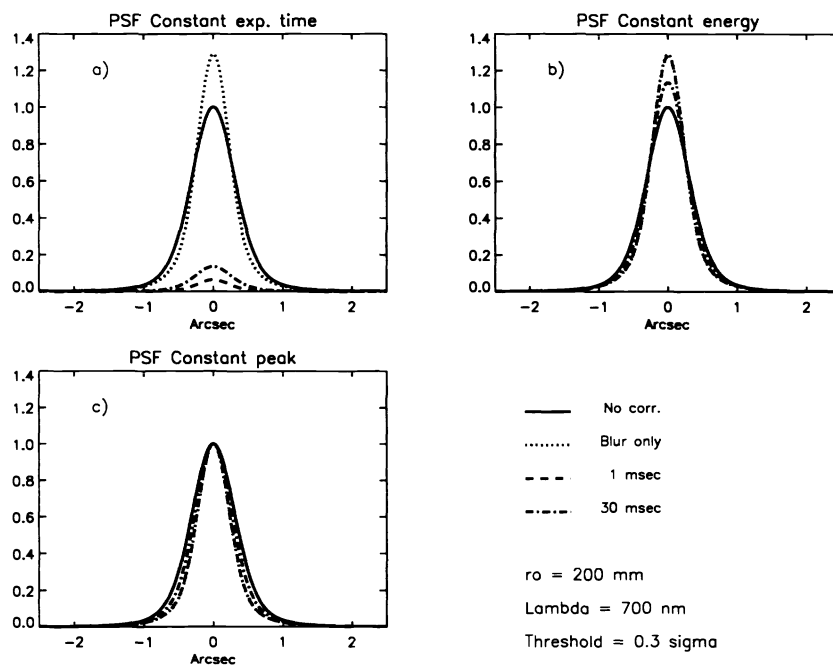


Figure 7: PSFs for images obtained with no-selection, no-Jitter and two different fast shutters

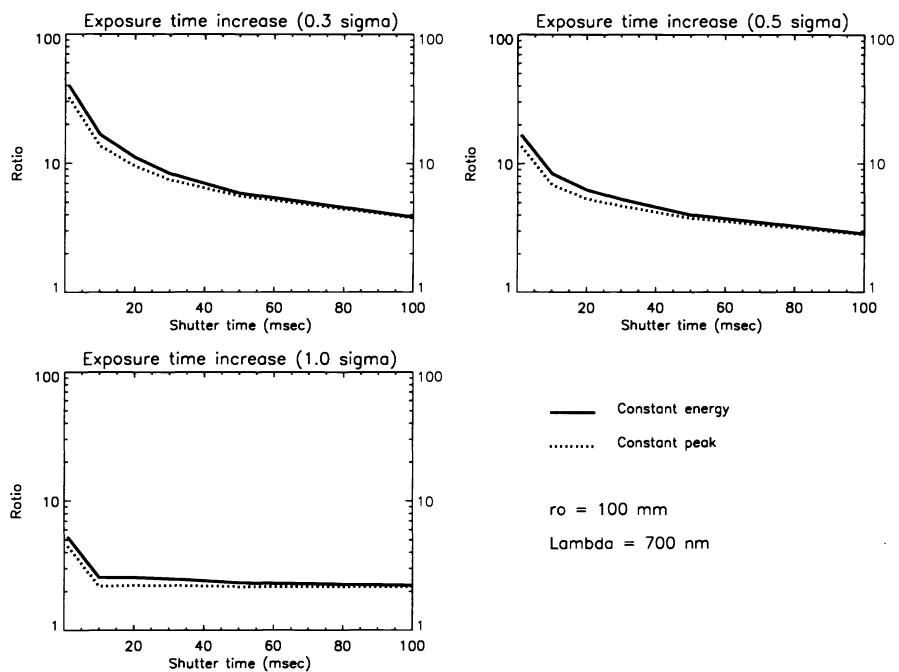


Figure 8: Increase in nominale exposure time to compensate for image rejection losses

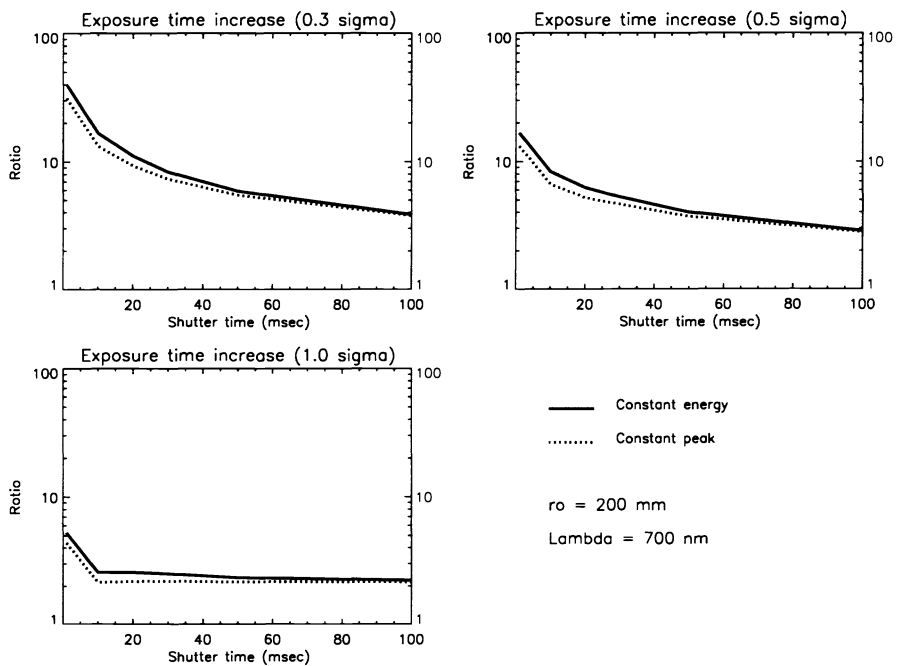


Figure 9: Increase in nominal exposure time to compensate for image rejection losses