# Inertially-Aided Image Stabilization

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## ABSTRACT

Raw images from telescopes, where the dome moves with the aperture, have been observed to be much less resolved than telescopes without a dome. This degradation is much larger than can be explained by diffraction related to aperture size. One likely cause is the higher vibration environment associated with dome motion. Dome seeing is another possible cause. Assuming the vibration environment is a major contributor to degradation in a staring, imaging system, a simplified optical inertial reference may greatly increase imaging performance when combined with postprocessing. This work will establish feasibility of post processing and real time, image stabilization techniques using the collimated light source projected from a simplified inertial reference in place of a star.

## 1.0 INTRODUCTION

An optical inertial reference is an inertially stabilized platform with an integral collimated light source that traverses the same path in an imaging system as the image. The use of an inertial reference with an integrated optical source is not new and has been at the heart of almost every directed energy (DE) system on a moving platform. When attempting to put a beam of energy on a target, it is necessary to use the information from the inertial reference along with target track information in real time over a very broad frequency band to stabilize the optical line of sight using fast steering mirrors and an inertially stabilized gimbal. In the case of imaging in a high vibration environment, the problem is much less difficult, as the camera filters out low frequency motion and the lowest frequency which a useful reference must appear stable above is inversely proportional to the exposure time. Images and information from the reference can also be stored and corrected in a post processing mode, which is not possible in a DE system. A schematic of an imaging system with a simplified inertial reference is shown in Figure 1. The point of light shown in the schematic contains information about blurring of the image due to motion induced by vibration of the telescope and can be used to aid in posprocessing.

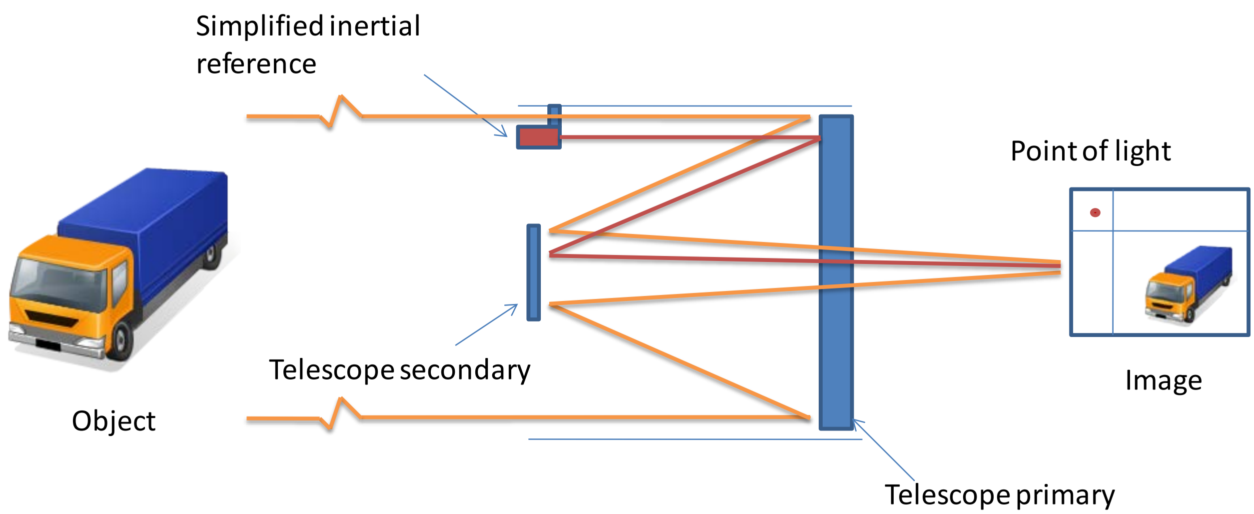


Figure 1 – Imaging system with simplified inertial reference

Assuming LOS jitter is controlled enough to keep the target on the image plane, the inertial reference only has to appear inertially stable above roughly half the sampling frequency to reduce jitter over the integration time of the image. The cost and complexity are inextricably linked to very low frequency performance in a traditional optical inertial reference, so the inertial reference for a staring, imaging system does not have to be complex or expensive and may be as simple as a passively isolated pointing laser.

## 2.0 Analysis

A finite element model of a large, ground telescope shown in Figure 2 was generated with a representation of a mechanically isolated probe beam. The isolation frequency was set to 5 Hz.

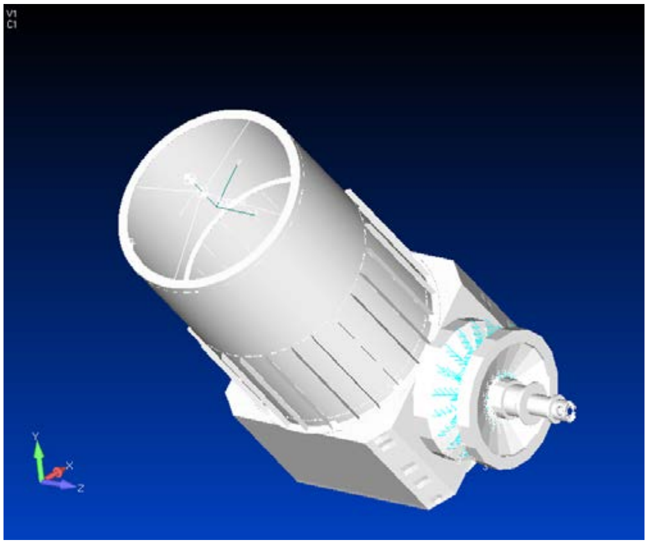

Fig. 2 – Finite element model of a large telescope with mechanically isolated probe beam

A modal analysis performed using the finite element model along with optical prescriptions of both the imaging path and the IRU beam path were used to generate a state space model. The input to the state space model was torque on the elevation axis and the outputs were jitter on each of the optical paths. This jitter was a combination of the motion of the 6 degree of freedom motion of the optical components times the optical sensitivities derived from the optical prescriptions. A transfer function generated from the state space model relating jitter along each optical path and torque input to the elevation axis is shown in Figure 3. The resonance of the mechanically isolated beam indicated on the IRU path in Figure 3. Other differences in the IRU path and the image path are clearly evident at low frequencies, but the paths appear to converge at around 50 Hz. Assuming a camera that is sampling the imaging path at 100 Hz, similarities between the paths above ~50 Hz mean that the information from the iru path could be used to correct the image path either by feedback control or postprocessing.

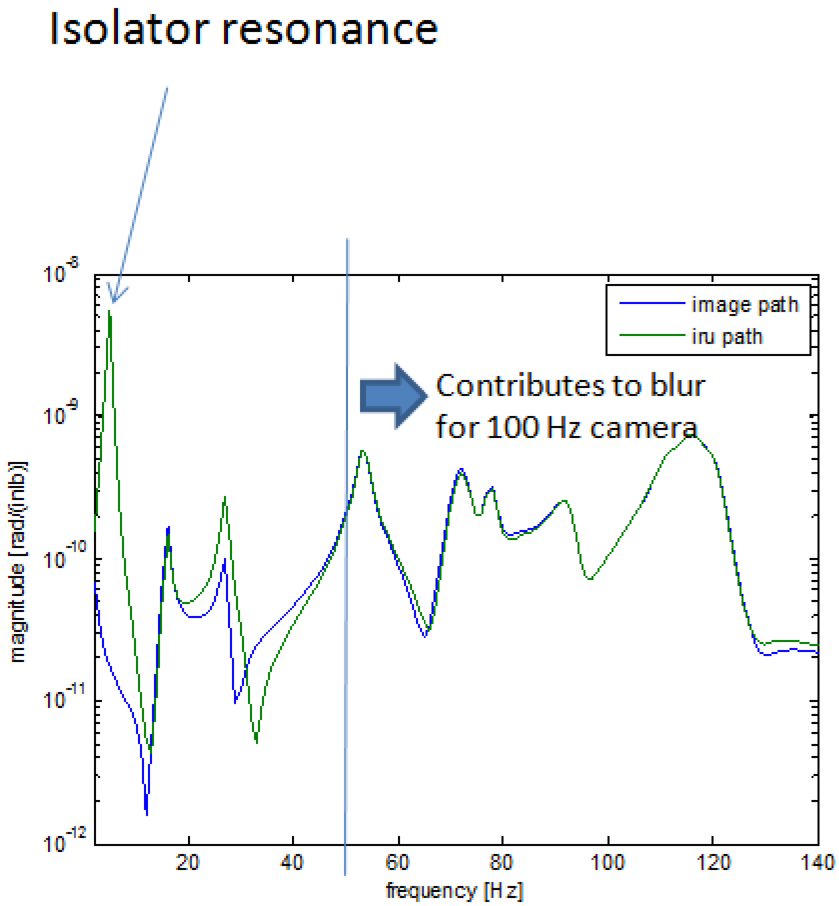


Figure 3 – Transfer functions generated from state space model

To investigate the potential of correction of the image path using the iru path, a feedback control loop using a commercially available fast steering mirror was simulated. Disturbance inputs were based on measured vibration data from a representative telescope. The feedback loop was designed to perform at frequencies above 50 Hz and do nothing at frequencies below 50 Hz. The results are shown in Figure 4. The closed loop amplitude above 50 Hz is greatly reduced by the feedback loop. In the case of an imaging camera with a 100 Hz sample rate, this would reduce image blur due to vibration.

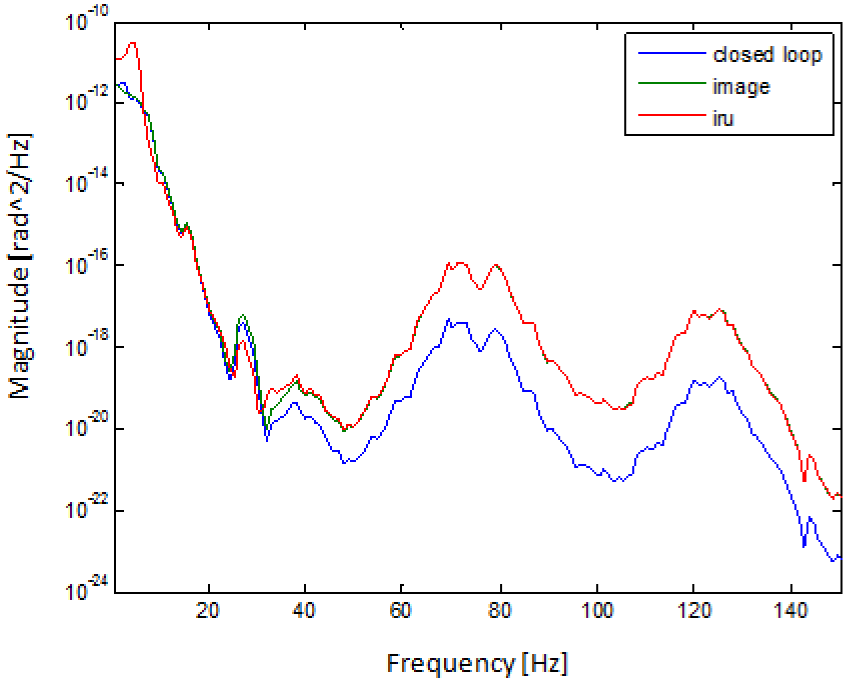


Figure 4 – Control results

An imaging simulation was also performed using the results from the vibration analysis. This simulation included an atmospheric path with $r_0$=4 cm (at 500 nm), a 1.6 m aperture, and a critically-sampled imaging camera at 750 nm. This simulation included the previously described base vibration and closed loop control to decrease image blur due to base vibration. It is important to note that it did not include atmospheric tilt correction: compensating for atmospheric tilt will blur out the high-spatial-frequency information encoded in the speckle pattern, reducing the achievable image quality. The simulated data frames were fed through a bispectrum algorithm to produce reconstructed images that can be visually compared to understand the impact of the vibration loop on the full imaging chain. Results from the simulation using a resolution target shown in Figure 5 indicate that the closing a feedback control loop on the probe beam on the IRU path improves reconstructed imagery, and that this improvement becomes more apparent at lower signal levels.

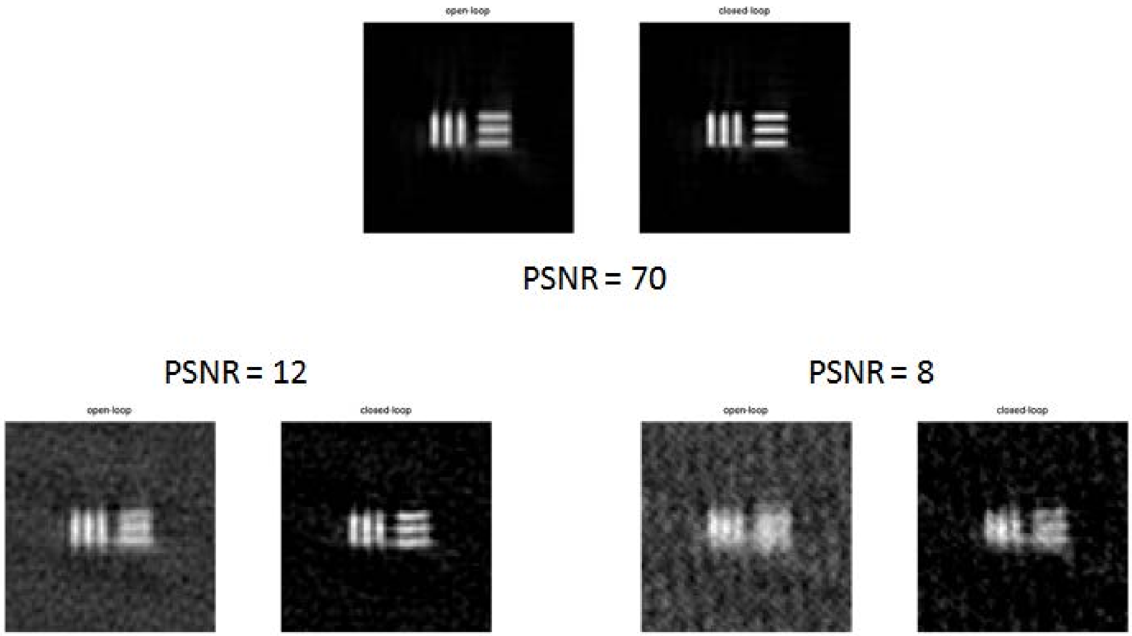


Figure 5 - Closing loop improves reconstructed imagery

## 3.0 CONCLUSION

A detailed simulation of a large telescope in a relatively harsh vibration environment was performed. The simulation used a finite element model, measured vibration data and optical prescriptions to derive jitter due to the base vibration environment. This behavior was combined in an imaging simulation with the degrading effects of the atmosphere. The simulation showed that a simplified inertial reference can be used to greatly improve reconstructed imagery from a telescope with significant base vibration.