SPACE TELESCOPE MOTION LIMITATIONS FOR FINE GUIDANCE SENSOR ASTROMETRY

Alain Fresneau*
Space Telescope Science Institute
3700 San Martin Drive
Homewood Campus
Baltimore MD 21218

ABSTRACT *Basic Fine Guidance Sensor data have been simulated to correlate the Power Spectrum Densities (PSD) of the Space Telescope motion disturbances with the "seeing" of an astrometric target. The goal of this study is to describe whether a complete identification of the jitter of the line of sight during an astrometric observation is required to improve the precision of this observation. The present preliminary results indicate that the performance in Astrometry are close to the predictions.*

INTRODUCTION

The limitations of the Edwin P. Hubble Space Telescope motion for Fine Guidance Sensor Astrometry will not be known before the deployment of the spacecraft when the mechanical interaction of the support system module with the Reaction Wheel Assemblies will be correlated with the data of the sensors used for guidance. The Astrometric Data Reduction Software (*Jefferys 1986*) which is implemented at the Space Telescope Science Institute as part of the Scientific Data Analysis Software is an opportunity to test simulated Fine Guidance Sensor data and to identify the modules of time series analysis suitable to a statistical analysis of the data flow sensitive to the attitude stabilization of the spacecraft . The present study is an attempt to describe the overall effect of the Space Telescope motion on the readings of the Fine Guidance Sensor devoted to Astrometry .

SPACE TELESCOPE MOTIONS

There is an almost complete reliance on analysis rather than experimentation to determine the jitter budget, which is basically a list of structural responses to the disturbances sources with their frequency spectrum. This budget, based on valid, but not worst case estimates, may be misleading and the present initiative is to study the impact on Astrometry of different jitter specifications under various operational scenarios. The Reaction Wheel Assemblies constitute the main forcing function for structural ringing but are supposed to introduce a very small jitter if they are kept below a 10 Hz rate . This specifies in turn an upper bound for momentum storage. Very low frequency disturbance sources due to the Solar

* Affiliated with the Astrophysics Division, Space Science Department of ESA

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Array flexure will be sensed by the controller of the pointing system (*Dougherty, Tompetrini, Levinthal and Nurre 1982*) and will be nulled out, while high frequency disturbances will not. An uncalibrated gyro drift of 0.″003 per second has also been assumed in the present simulation of the motion of the Space Telescope.

SIMULATION OF THE FINE GUIDANCE SENSOR DATA

The basic data are PMT counts and star selector encoder readings at a sampling rate of 40 Hz. The interferometer is kept near its null position by active servos and the wavefront tilt data are used to develop pointing error signals which are used to provide an attitude reference for the Space Telescope at a sampling rate of 1 Hz . In the Fine Guidance Sensor used for Astrometry, the servos are kept at a null rate in order to integrate over a time longer than 0.025 seconds and then are moved at the position to null the error signal (*Jefferys 1980*). This pattern of "integrate-then-move" is repeated 32 times and the astrometric measurement is the mean value of the 32 readings. In this study, I have generated 50 observations of targets of visual magnitude 15, 16, and 17 with Guide Stars of visual magnitude 13 and 12. The processing whithin the Fine Guidance Sensors results in polar coordinates of star images in the Field of View of the Space Telescope (*Duncombe, Benedict, Hemenway and Jefferys 1982*). The present numerical studies will allow a more comprehensive assessment of the bandwidth of the error budget for Astrometry.

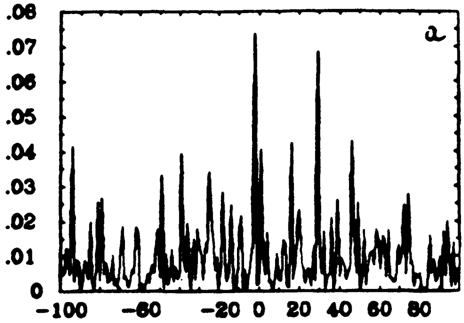
VEHICLE ATTITUDE

The mean PSD of the jitter generated for each of the 50 samples is given in Figure 1a .

The frequency resolution is 0.2 Hz and the specific frequencies introduced in this simulation appear clearly. To the jitter noise is added the photon statistics in the sensor locked onto the Guide Stars and the mean PSD of the feedback signal (Figure 1b) shows that most of the signal is dominated by the Poisson noise: the magnitude of the different harmonics is rather small. The cross PSD of these two signals (the input jitter and the signal commanded as output) shows (Figure 1c) that they are interdependent only at some frequencies: this means that pure signal and noise process are then correlated. Rigorous study would be necessary to evaluate the fine lock performances in presence of two sources of noises (gaussian and Poisson) which are correlated: one Guide Star is used to control the roll and the other one determines the pitch and yaw simultaneously.

BIVARIANT ANALYSIS

In time-series analysis, bivariant analysis can be used to establish a mathematical connection between a system's input and output and to define the interrelation between signal pairs. In order to study the Fine Guidance Sensor performances, the transfer function (Figure 2a) describes the input-output behavior in the frequency domain. It can be abstracted from this study that the sensor has an impulse response at low frequencies: this information proves the integrity of the simulation performed about bandpass capabilities.



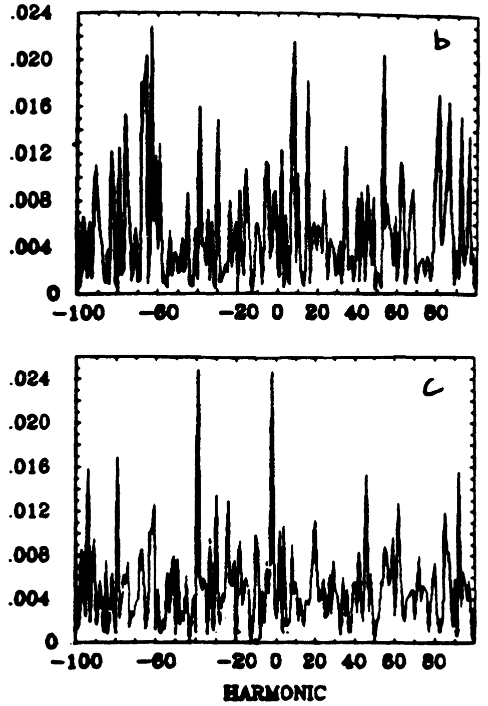
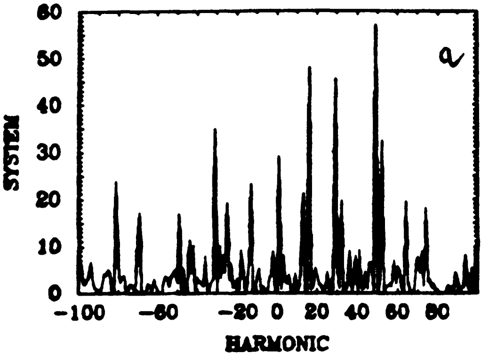


Figure 1. Discrete PSD in 0.″001^2 per 2 Hz versus the harmonic numbers of a period of 60 seconds for the simulated input signal (a), the feedback signal (b) sensed by the Guide Stars, and their cross- power spectrum (c) .



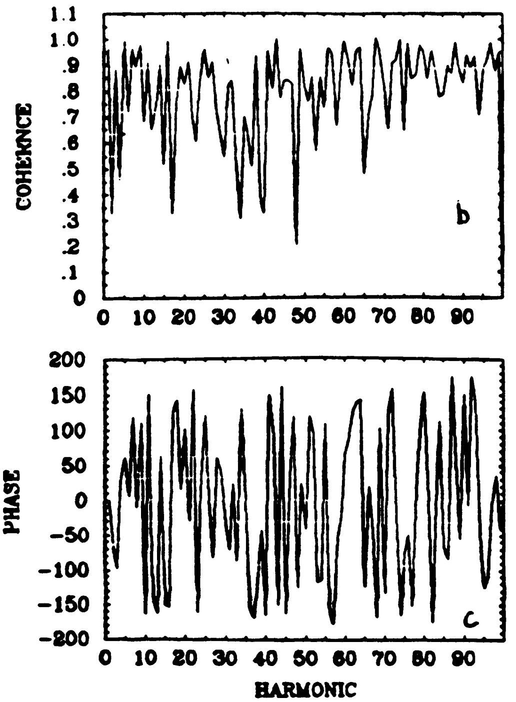


Figure 2. The simultaneous study of the input and output signals is investigated by the system transfer function (a), the coherence (b) and the phase spectrum (c) versus the harmonic numbers of a period of 60 seconds of time.

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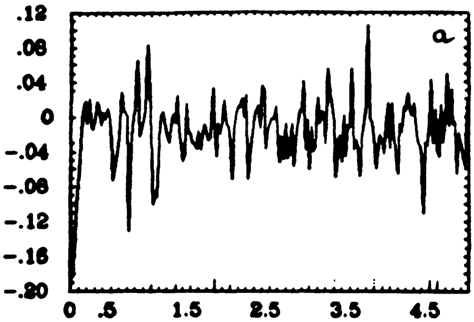

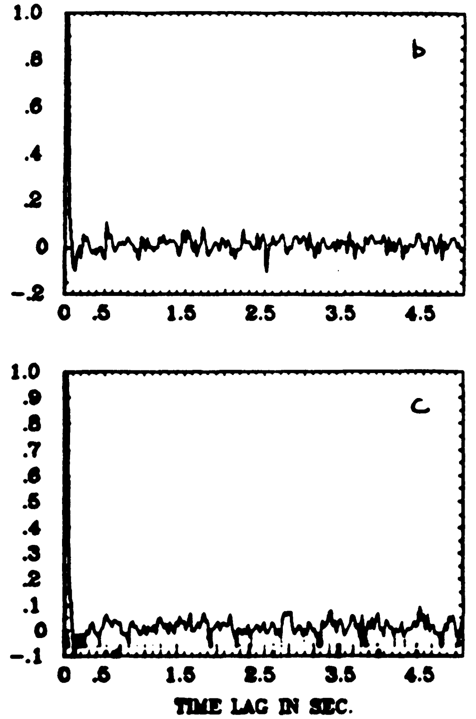

Figure 3. The consecutive locations of an astrometric target image in the focal plane are studied by the autocorrelation of the measured radius (b) and azimuth (c) and their crosscorrelation (a) versus the time lag in seconds of time.

At low frequencies, the output is dominated more by pure signal power than by noise power. To test the system having in mind noise sources, nonlinearities and multiple inputs, the coherence function (Figure 2b) exhibits a high degree of causality or feedback, measuring the effects of internal noise on the input-ouput relationship. The phase diagram (Figure 2c) exhibits that the angles of phase are near -180 degrees at the frequencies where the coherence is not very high. This information is needed to interpret correctly the coherence function: when the phase angle is -180 degrees, the correlation between the input and output is equal to -1 . These plots control the simulated phenomenon of adding signal and noise which are not independent.

BEHAVIOR OF THE ASTROMETRIC DATA

The polar coordinates (radius and azimuth) of the astrometric target image in the focal plane are corrected from the information given by the sensors used for guidance at a rate of 40 Hz. These data are then investigated by their cross-correlation (Figure 3a), the autocorrelation of the radius (Figure 3b) and of the azimuth (Figure 3c).

It is obvious that the correlation time is very short. The r.m.s. error of each component is found in these tests to stay in the range of 0.004 to 0.005 arcsec. The r.m.s. error of the 32 values of each component, not corrected by the update of the line-of-sight, is found to reach the same level of accuracy. An individual analysis of the data of the sensors used for guidance does not therefore improve the internal accuracy. Further studies are needed to demonstrate the extension of the integration time on fainter target with nonlinear measurements characteristics of the signal processing. The present results may well just recognize the limitations of a linearized analysis and the implications are beyond the scope of this limited simplified study.

CONCLUSION

The purpose of this paper was to describe the basic approaches to deal with the problem of the influence of the light of sight motion on Astrometry with the Fine Guidance Sensor. The structural parameters and the vibration effects will be experimented during the Assembly and Verification period of the Space Telescope. A better identification of the correct magnitude of disturbance noises will then be possible. The Astrometric Data Reduction Software is quite appropriate to the user and the quality of the observation will be checked by the external accuracy of the measurements, and not by an analysis of the jitter. Therefore, I conclude by suggesting that the correlation analysis and spectral density estimation are just the basic tools to a visual inspection, not model oriented, of the performance of an astrometric observation influenced by jitter and photon noise.

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