Attitude Control of a Large Flexible X-ray Telescope using Wave-based Control

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Introduction

X-ray telescopes act as our eyes in viewing the hot and energetic universe. They can explore the physical conditions around Supermassive Black Holes and map the large scale structure of our universe. The size of the smallest object they can resolve is directly related to the telescope's focal length, leading to long deployable structures which inevitably are flexible. This paper examines attitude control of one such design, the proposed International X-ray Observatory (IXO), designed for a deployed focal length of 20 m [1].

Motivation

When positioning the telescope, very small angular resolutions are sought, in the order of 10 arcsec, to provide sufficient measurement sensitivity. If this angular resolution can be further reduced it provides a mission with a significantly enhanced science capability, for example allowing sampling of the lower luminosity Active Galactic Nuclei (AGN) [2]. Vibrational modes excited during the slewing, pointing or dithering of the telescope can cause these tight positioning limits to be exceeded. There is therefore a need to control modes of vibration excited during repositioning manoeuvres.

Model

The IXO structure comprises a main service module, on which all thrusters and reaction wheels are mounted. An instrument platform is held at some 10.5 m away by a light, inherently flexible, deployable interconnecting structure consisting of 3 light booms, hinged at their mid-points, the main source of the flexibility. A flexible multibody model of the IXO was developed by ESA in DCAP, and made available for this analysis. See Figure. 1. Actuation for attitude control was provided by five reaction wheels, producing very modest torques of 0.4 N.m and angular momentum capacity of 150 Nm, for a structure of large inertia (typical moments of inertia [3.6 E05,3.6 E05,12 E03] kg.m^2)

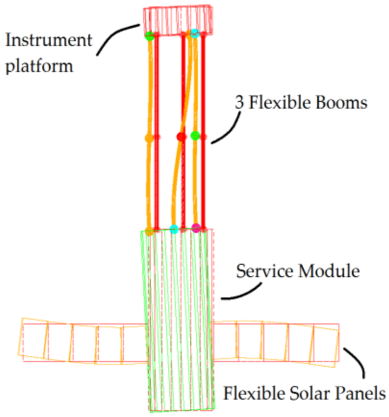

Figure. 1 Multibody model of proposed International X-ray Observatory showing torsional 1st elastic mode of the articulated boom.

Implementation

Wave Based Control (WBC) is designed to achieve precise, rapid, robust and completely stable motion control of under-actuated flexible structures. It used the methodology of launching and absorption of mechanical waves, to allow rapid repositioning while simultaneously controlling vibration. This paper builds upon previous successful applications of WBC to control 1-D mass-spring strings and 2-D planar mass-spring arrays [3, 4] and extends its application to 3-D attitude control of a flexible multibody model representative of the proposed IXO structure in a space environment. To produce the results shown, additional challenges were overcome, arising from the cross coupling of motion around different axes, a floating (ungrounded) actuator, perturbation torques and sensor noise.

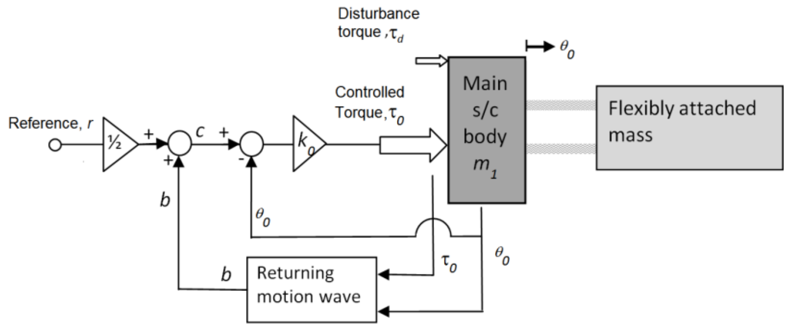

Figure 2 Schematic of WBC loop for control of a X-ray telescope with flexible appendages.

A wave based control loop, as in Figure 2, was set up for each of the 3 rotational axes, implementing the following equations:

$$\tau_0 = k_0(\tfrac{1}{2}r + b - \theta_0) \tag{1}$$

$$b = \left(\frac{\theta_0 - \tau_0(G_{T2D})}{1 + (G_{D2T})(G_{T2D})} \right) G_{D2D} \tag{2}$$

where θ_o, τ_o and τ_d are the angular displacement, control torque and disturbance torque associated with the IXO service module, r is the reference angular displacement, k_0 is a tuneable parameter related to the system stiffness, b is the calculated "return wave", G_{D2D} is a "wave transfer function" (*WTF*) with a displacement input and displacement output, G_{T2D} is a torque input, displacement output *WTF* and G_{D2T} is a displacement input, torque output *WTF*.

Results

WBC was tested using the developed flexible multibody model of IXO and was compared to two H-infinity robust controllers (H_∞ #1 and H_∞ #2) presented in [5]. H_∞ #1 controller does not take into account any plant uncertainty and is designed for speed. It is less robust than H_∞ #2 which is slower but designed to cope with plant uncertainties (in inertias, eigen-frequencies, damping ratios…).

	WBC		**H_∞ #1**		**H_∞ #2**	
Amplitude	**Slew Time (s)**	**Time to settle (s)**	**Slew Time (s)**	**Time to settle (s)**	**Slew Time (s)**	**Time to settle (s)**
1°	245	5	604s	364	1200s	960
35°	1722	5	2128s	411	3258s	1541
120°	4972	5	5456s	478	6300s	1322
180°	7278	5	7494s	214	8500s	1220

Table 1 –Performance comparison for different slew manoeuvres of WBC against two robust controllers.

Table 1 shows the manoeuvre times for a range of slew angles. The "time to settle" is here defined as the time above the minimum time for the corresponding "rigid-body" manoeuvre involving a time-optimal, max-acceleration-coast-max-deceleration profile. Because WBC controls the vibrations also during the transient, it can make the flexible structure move as if almost rigid for most of the transit, leading to quicker slew times than are possible using the H-infinity robust controllers.

References

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