Spacecraft Attitude Motion and Control

Introduction

Spacecraft missions involve many tasks e.g. navigation, communication, surveillance etc., which require a specific inertial attitude. In addition, spacecraft contain many components e.g. solar arrays, sun / star sensors, which also need to maintain a specific attitude. The problem of maintaining attitude is complicated by the fact that spacecraft orbits/ moves along a path, which may have varying inertial orientations.

Spacecraft Missions and Attitude Motion

Spacecraft missions involve many tasks e.g. navigation, communication, surveillance etc., which require a specific inertial attitude. In addition, spacecraft contain many components e.g. solar arrays, sun / star sensors, which also need to maintain a specific attitude. The problem of maintaining attitude is complicated by the fact that spacecraft orbits/ moves along a path, which may have varying inertial orientations. In most cases, spacecraft need to point in any one of the following directions i.e. earth pointing, inertial or star pointing and sun pointing. Earth pointing requirement primarily comes from communication and broadcast satellites, which are geostationary / geosynchronous in nature. Inertial or star pointing requirement arises for inter-planetary objects (e.g. Hubble Space Telescope), which need to focus on a star for several hours. Sun pointing requirements are applicable for most objects and arise from power considerations (battery charging), orbit drift corrections (solar radiation) etc. However, in specific cases (e.g. SOHO, ADITYA-L1), sun pointing is also employed for observing specific features of sun such as its corona, solar wind etc. Lastly, we need to ensure the required attitude when the spacecraft is in orbit or is on an interplanetary path.

Spacecraft Pointing Scenarios

Most of pointing exercises involve the following three tasks i.e. Attitude Determination, Attitude Prediction and Attitude Control. Attitude determination is the process of computing spacecraft attitude with respect to an inertial reference or any object of interest e.g. earth, sun etc. This task requires a set of appropriate sensors and sophisticated processing techniques. Attitude prediction is the process of forecasting the future orientation using dynamical models and attitude history. Quality of this task depends on the accuracy of models as well as solution algorithms. Attitude estimation is an integral part of attitude prediction, which also takes inputs from sensors. Lastly, attitude control is the process of orienting the spacecraft in the desired direction and typically involves two sub-tasks; stabilization and manoeuvre control. Stabilization task is mainly to hold a fixed attitude, but if the reference changes then, we also need active control to ensure the desired attitude. It is clear that a number of actuation systems are required to achieve both stability and control of attitude.

Attitude Dynamic and Control Context

It is clear that to achieve the desired attitude, we need suitable rotations about spacecraft centre of mass. This brings in to focus, the angular (or attitude) motion of the spacecraft that needs to be analyzed. In reality, spacecraft is neither a monolith nor a rigid body and, hence, needs to be modelled as such. However, we find that at first, assumption of spacecraft as a single rigid body provides good solutions for dynamics. In case we need more accurate solutions (multiple bodies, structural flexibility), we can include these effects through simplified modifications to single rigid body solutions. Lastly, we also need to examine control options that are available for ensuring the desired attitude.

Course Objectives

To understand principles governing the attitude motion of spacecraft and applicable models.

To discuss various tools for attitude determination & prediction/ estimation.

To explore the various control options in the context of applicable sensors and actuators.

Course Contents

Preliminaries: Review of basic rigid body dynamics and applicable space environment. Attitude Kinematics: Angular velocity in rotating frames, direction cosines and quaternions based models. Basic Attitude Dynamics: Inertia matrix and principal inertia, Euler's equations. Single and three-axis attitude dynamics, single and dual-axis spin spacecraft models. Attitude Determination: Single-axis/ three-axis attitude determination. Attitude estimation with TRIAD, QUEST. Attitude Sensors/ Actuators: Gyros, Star trackers, sun sensors, horizon sensors. Reaction wheels, thrusters, magneto-torquers, CMGs etc. Attitude Control: Single- & three-axis spin stabilization, attitude control strategies. In-orbit attitude control with precision pointing and tracking.

Pre-requisites

Course does not have any formal pre-requisites. However, good familiarity with basic orbital mechanics is useful. Further, some understanding of elementary control concepts is desirable.

Text/References

Kaplan, 'Modern Spacecraft Dynamics & Control', Wiley India Edition, 1976.

Wertz (Ed.), 'Spacecraft Attitude Determination and Control', Kluver, 1978.

Hughes, 'Spacecraft Attitude Dynamics', John Wiley, 1986.

Rimrott, 'Introductory Attitude Dynamics', Springer-Verlag, 1989.

Sidi, 'Spacecraft Dynamics & Control', Cambridge, 1997

Markley & Crassidis, 'Fundamentals of Spacecraft Attitude Determination and Control', Springer, 2014.