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Author: Dr. Zhili Hou
Tsinghua University, China, hzl1334123@163.com

Dr. Simeng Huang
China, simenghuang@outlook.com

OPTIMAL STEERING LAW FOR SINGLE-GIMBAL CONTROL MOMENT GYROSCOPES WITH SINGULARITY AVOIDANCE AND VIBRATION SUPPRESSION

Abstract

Earth observation satellites, which are used for environmental monitoring, meteorological predicting, mapping, etc., are usually placed in the Low Earth Orbit (LEO) to provide satellite imagery at high resolution. The consequent short visibility window imposes the requirement of rapid attitude manoeuvre for many Earth observation missions. Single gimbal control moment gyroscope (SGCMG) is an ideal actuator for rapid attitude manoeuvre satellites because it can provide large and accurate torque. However, the singularity problem has always been the major factor that restricts the application of SGCMG. In addition to the rapid attitude manoeuvre, a high control accuracy after manoeuvring is also required to ensure the quality of photography. But in real applications, the control accuracy is sometimes influenced by the residual vibration due to flexible appendages (e.g. solar panels) at the end of manoeuvring. Many studies have been conducted to address the problems of singularity and residual vibration. For singularity avoidance, the typical approaches are adding null motions, allowing certain degrees of torque errors, weighting null motions and torque errors, giving initial guess for gimbal angles, etc. For vibration suppression, the effective methods are the input smoothing, the optimal s-curve motion profiles, etc. However, in previous study, the problems of singularity and residual vibration were solved separately, while there is a mutual limit between these two problems. If the singularity problem is not considered when designing the vibration suppression trajectory, the trajectory will very high likely lead the motion of SGCMG to singularity state. If the residual vibration is not taken into account when designing the SGCMG steering law, a large vibration may be excited. The novelty of this paper is developing a SGCMG steering law able to avoid the singularity and suppress the residual vibration at the same time. The idea is to introduce a hybrid performance index to evaluate both the singularity avoidance and vibration suppression performances. In this hybrid performance index, a weighting coefficient is assigned to the singularity avoidance performance to measure the degree of the detachment from the singularity surface. By using the theory of the calculus of variations, the hybrid performance index can be minimized and the analytical solution for the SGCMG steering law can be derived. A preliminary study has been done by the authors. The simulation results show that the proposed steering law can globally minimize the gimbal rates and efficiently suppress the residual vibration down to almost the natural frequency.