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Applications of advanced controlmethods in spacecrafts: progress, challenges, and future prospects

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Motivation

We aim at examining the current status of advanced control methods in spacecrafts from an engineer's perspective. Instead of reviewing all the fancy theoretical results in advanced control for aerospace vehicles, we focus on the advanced control methods that have been practically applied to spacecrafts during flight tests, or have been tested in real time on ground facilities and general testbeds/simulators built with actual flight data. It is hoped that this review paper will enlighten aerospace engineers who hold an open mind about advanced control methods, as well as scholars who are enthusiastic about engineering-oriented problems.

Main idea

- Members of the control community are quite enthusiastic about developing novel and fancy control methods. But in aerospace engineering, more than 99% launched spacecrafts are still using PID. We concluded three probable reasons :

  1. Lack of a control-oriented model;
  2. Lack of perspective from engineers;
  3. Expense of computation.

Main idea

- In modern aerospace engineering, the main focuses in attitude control are high precision and fast maneuverability. With these increasing demands and the new generations of satellites, the main difficulties for spacecraft attitude control are

    1. Flexible structure;
    2. Unknown parameters;
    3. Changing parameters;
    4. High-level requirements.

Main idea

- We concluded several main advanced control laws that have been applied on-orbit or through ground tests with flight data. These advanced control laws include optimal control, adaptive control, and robust control.

1. Linear quadratic regulator;
2. Inverse optimal control;
3. Pseudo spectral optimal control;
4. Model reference adaptive control;
5. Characteristic model-based golden-section adaptive control;
6. H_∞ and H_2 control;
7. μ synthesis.

Main idea

- Flexibility is probably the biggest challenge in spacecraft control. Four well-known satellites that use advanced control methods to suppress the flexible modes are introduced in this paper.

  1. Spacebus 4000 telecommunication satellite;
  2. Engineering Test Satellite-VI/VIII;
  3. Hubble Space Telescope.

Main idea

- We also focuses on the situation with unknown parameters, where identification and adaptive control algorithms are developed for two satellites and one onboard experiment. Three pacecrafts with unknown parameters are introduced in this paper:

  1. Shenzhou spacecraft;
  2. Data Relay Test Satellite;
  3. Middeck active control experiment.

Main idea

- During the reentry of spacecrafts, the unknown and fast-changing environment poses a huge challenge to the control system. Much effort has been made to deal with the parameter changes. Four Reentry spacecrafts with changing parameters are introduced in this paper:

  1. Italian Unmanned Space Vehicle;
  2. Middeck active control experiment;
  3. Shenzhou reentry module;
  4. Chang’e 5 test spacecraft.

Main idea

- Nowadays, high-performance requirements are required for spacecrafts. Optimal control methods are introduced to meet those requirements. Four kinds of spacecraft with different kinds of mission requirements are introduced in this paper.

  1. Reorientation of the International Space Station;
  2. Reorientation of the Transition Region;
  3. Fast maneuver of the SSTL microsatellite;
  4. Accurate pointing of FASTSAT.

Conclusion

- We provided a thorough review on the practical applications of advanced control methods in satellites and reentry spacecrafts. These spacecrafts and their advanced control laws are summarized in Table 1 (see the next page). This table reveals some valuable and interesting disciplines:

1. Flexibility;
2. Uncertainties;
3. Changing parameters.

Conclusion (con't)

Table 1 Spacecrafts with advanced control methods and the time when they were applied to the corresponding spacecrafts

Character	Spacecraft	Optimal control			Adaptive control			Robust control	
		LQR	Inverse optimal	PS	MRAC	Self-tuning	CM-GSAC	H_∞/H_2	μ
Flexible structure	Spacebus 4000							2003+	2003+
	ETS-VI	1995						1995	
	ETS-VIII							2009; 2010	2009; 2010
	HST (simulation)	1995						1995	
Unknown parameters	Shenzhou RVD						2011; 2012		
	MACE	1995						1995	
	DRTS					2002			
Changing parameters	Space Launch System				2009+				
	Chang'e 5T						2014		
	Shenzhou reentry						1992+		
High-level requirements	ISS			2007					
	SSTL (simulation)		2011						
	TRACE			2010					
	FASTSAT	2010							