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Vesoljska tehnika - Smernice za nadzor delovanja

Space engineering - Control performance guidelines

Raumfahrttechnik - Richtlinien für Leistung von Regelung/Steuerung

Ingénierie spatiale - Lignes directrices des performances du contrôle

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Space engineering - Control performance guidelines

Ingénierie spatiale - Lignes directrices des performances du contrôle

Raumfahrttechnik - Richtlinien für Leistung von Regelung/Steuerung

This draft Technical Report is submitted to CEN members for Vote. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

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Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

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European Foreword

This document (FprCEN/TR 17603-60-10:2021) has been prepared by Technical Committee CEN/CLC/JTC 5 "Space", the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-60.

This Technical report (FprCEN/TR 17603-60-10:2021) originates from ECSS-E-HB-60-10A.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

This document is currently submitted to the CEN CONSULTATION.

Introduction

This document focuses on the specific issues raised by managing all performance aspects of control systems in the frame of space projects. It provides a set of practical definitions, engineering rules, recommendations and guidelines to be used when specifying or verifying the performance of a general control system; attention was paid by the authors to keep the application field as open as possible, and not to restrict to a specific domain – such as spacecraft attitude control for example.

It is not intended to substitute to textbook material on automatic control theory. The readers and the users are assumed to possess general knowledge of control system engineering and its applications to space missions. Nevertheless when required – to avoid any risks of ambiguity for example, or for the clearness of the presentation – some basic definitions and rules are provided in dedicated annexes.

This document was originally intended to focus on the specific case of pointing systems and AOCS, starting from an existing ESA handbook [Pointing Error Handbook, ESA-NCR-502], to be updated, completed, and extended to be built up as an applicable ECSS document. But after reviewing the scope, this approach appeared somewhat restrictive:

- restricting performance concepts to "pointing" does not allow to deal with problems such as thermal control, position control (robotics), or more generally any other type of control systems, even though these problems share the same theoretical framework;

- AOCS is one major contributor to the overall system pointing performance, yet not the only one: misalignments, thermoelastic effects, payload behaviour, etc. all contribute to the final performance. This remark can be extended to general systems, considering that the controlled part is but one of the contributors.

Accounting for these remarks led to extending the initial scope of this document. The upgraded objective is to set up a generalised framework introducing performance definitions, performance indices and budget calculations. "Generalised" is understood here in two directions:

- transversally, so as to be applicable independently on the physical nature of the control system (not only pointing),
- and vertically, in the sense that in many practical situations the proposed definitions and techniques can also apply to any part of the system (basically to the controlled part, but not restrictively). This should assure consistency between the performances indices (error budgets) of the complete system and of the controlled system part. Motivation is also that dedicated but generic methods for budget breakdown can be applied on different levels i.e. on system level and on controlled system level.

NOTE 1 The idea of defining a general framework applying from equipment level to system level is driven by a concern for technical and conceptual consistency. In a later phase, relevant system aspects can be transferred or copied to the appropriate System Engineering standard – if found more convenient.

NOTE 2 The general control structure from the Control Engineering handbook [ECSS-E-HB-60A, Figure 4-1] has been extended in support, showing also the system performance in the output (Figure 4-2 of this handbook)

NOTE 3 The objective of this document is not to cover the high level system or mission performance aspects, which clearly belong to a different category.

In addition to this will for general and generic concepts, a clause of this document covers the performance issues which are more specific for the controlled systems themselves (mainly involving feedback loops in practice) or which are based on well-known control methods. The need for this clause arises as such systems call for particular technical know-how and feature specific performance indicators that require additional insight. For example: stability and robustness properties, transient responses (settling time, response time etc.) and frequency domain indicators.

Although this document is designed to be as general as possible, clearly in practice pointing and AOCS issues are the most demanding space engineering disciplines in terms of control systems. They are covered by an informative annex of the document which declines the general concepts and illustrates how pointing issues can be managed as a special case of vector-type data on a high resolution Earth observation mission.

Driven by a similar concern for illustration on space engineering applications of practical interest, another annex of the document shows how to decline the general concepts to deal with the control performance issue arisen by robotics applications.

1 Scope

This Handbook deals with control systems developed as part of a space project. It is applicable to all the elements of a space system, including the space segment, the ground segment and the launch service segment.

It addresses the issue of control performance, in terms of definition, specification, verification and validation methods and processes.

The handbook establishes a general framework for handling performance indicators, which applies to all disciplines involving control engineering, and which can be declined as well at different levels ranging from equipment to system level. It also focuses on the specific performance indicators applicable to the case of closed-loop control systems.

Rules and guidelines are provided allowing to combine different error sources in order to build up a performance budget and to assess the compliance with a requirement.

This version of the handbook does not cover control performance issues in the frame of launch systems.

2 References

EN Reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS System - Glossary of terms
EN 16603-10	ECSS-E-ST-10	Space engineering – System engineering general requirements
EN 16603-60-10	ECSS-E-ST-60-10	Space engineering – Control performance
EN 16603-60-20	ECSS-E-ST-60-20	Space engineering – Stars sensors terminology and performance specifications
TR 16703-60	ECSS-E-HB-60	Space engineering – Control engineering handbook
EN 16601-40	ECSS-M-ST-40	Space project management – Configuration and information management

3 Terms, definitions and abbreviated terms

3.1 Terms from other documents

For the purpose of this document, the terms and definitions from ECSS-S-ST-00-01 apply.

3.2 Terms specific to the present handbook

3.2.1 control performance (state)

quantified output of a **controlled system**

NOTE 1 Depending on the context, the control performance is realised either as **signal performance** or as **control loop performance**.

NOTE 2 Can also be applied to a **control system**.

3.2.2 control (performance) knowledge (state)

estimated **control performance** after measurement and processing, if any

NOTE The control performance knowledge is not necessarily the best available knowledge of the **control performance**. The achieved accuracy and the allowed deviation (control performance knowledge error) depends on the application.

3.2.3 control reference (state)

ideal reference input, desired state or reference state of controlled part of the plant

3.2.4 domain variable

independent variable which can be used to put some dependent quantity into a certain order

NOTE This comprises continuous time, discrete time, N-dimensional space, etc.

3.2.5 ergodicity

property of a stochastic process such that its ensemble and time statistical properties are identical. Ergodicity allows to transfer the statistical results of a single realisation of a stochastic process to the whole ensemble

NOTE (Weak) **stationarity** is prerequisite for (weak) ergodicity.

3.2.6 error index

parameter isolating a particular aspect of the time variation of a performance error or knowledge error

3.2.7 extrinsic performance

element of performance related to the response of the system to its interaction with the outer world (control reference signal, error sources and other disturbances)

NOTE 1 for example the pointing error of a satellite is relevant to this category of extrinsic performance (it depends on the disturbing torques and on the measurement noises)

NOTE 2 can also be defined in opposition to **intrinsic performance**

3.2.8 intrinsic performance

element of performance related to the intrinsic properties of the system, independently on its interaction with the outer world (control reference, the nature and the amplitude of the error sources and other disturbances)

NOTE 1 for example the **stability** of a closed-loop controlled system is relevant to this category of **intrinsic performances**

NOTE 2 can also be defined in opposition to **extrinsic performance**

NOTE 3 "I have some of my properties purely in virtue of the way I am. (My mass is an example.) I have other properties in virtue of the way I interact with the world. (My weight is an example.) The former are the intrinsic properties, the latter are the extrinsic properties" [Weatherson, Brian, "Intrinsic vs. Extrinsic Properties", The Stanford Encyclopedia of Philosophy (Fall 2004 Edition), Edward N. Zalta (ed.)]

3.2.9 individual error source

elementary physical characteristic or process originating from a well-defined source which contributes to a **performance error** or a **performance knowledge** error

NOTE For example sensor noise, sensor bias, actuator noise, actuator bias, disturbance forces/torques (e.g. micro-vibrations, manoeuvres, external or internal subsystem motions), friction force/torque, misalignments, thermal distortions, assembly distortions, digital quantization, control law performance (steady state error), jitter, etc.

3.2.10 performance error (state difference)

deviation of a performance from its reference; realised as **control (signal or control loop) performance** error or **system performance** error, depending on the context

3.2.11 performance error indicator (state difference)

any quantity suitable to define the **performance error** or **performance knowledge error** of a **controlled system** or one of its parts. Examples are signal error functions, signal error indices or control loop performance indicators