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Robust, fault tolerant, fractional order control strategies with application to isotope separation cascades

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Summary

The research of the last decade includes fundamental questions and challenges of control systems such as ***robustness***, ***stability***, and ***adaptability***, and ***cross-disciplinary*** endeavors in areas such as complex sensor networks, real-time and cognitive systems.

The control community is increasingly engaged in collaborative projects dealing with emerging concepts and themes, including ***cyber-physical systems*** with applications in areas like transportation networks and systems, energy conservation and efficiency, renewable energy integration in intelligent power grids, etc.

The present research is in line with these research trends, proposing to develop a ***new concept of an embedded complex control system addressing issues of sustainability, security and cyber-enabled reconfiguration inspired by Nature***.

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Summary

The final result of the project will be directly applied in the special field of isotope separation technology. Previous experiences in the control of single separation column proved the limits of conventional strategies, while for the cascade of three columns only an intelligent integration of fractional order, distributed, bio-inspired fault tolerant, robust system can be a viable solution.

The importance of the project is firstly emphasized by its applicative, practical nature, in a field of international interest, and by the frontier research character, related to the development of novel control strategies, with potential applicability to a multitude of emerging embedded systems.

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Objectives

The ***main objective of the project*** is to offer an efficient, fault tolerant, robust control method for emerging cyber-physical systems

The ***first objective*** refers to the broadening of robust, distributed control system theory, a subject that combines two emerging research domains: distributed control and robust control systems. Therefore, this first objective is focused on elaboration of novel approaches for the design of robust controllers based on fractional calculus for large scale, distributed systems.

Objectives

The ***second objective*** is specific for cyber-physical systems: the design of Multi Agent Systems (MAS) in order to obtain the desired fault tolerant control, to have aspects of robustness, reactivity and flexibility, which allow the control system to be powerful and to react to all the risks that may occur. The objective of the proposal is to develop a self organizing approach of the MAS, inspired by biology,

The ***third objective*** reveals the applicative nature of the project: applying the designed fault-tolerant, robust control system to the ^{13}C isotope separation column cascade in a Hardware in the Loop manner.

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Activities

The work plan consists of five work-packages which are divided in according to the specificity of the activities.

WP1: Project Management;

WP2: Dissemination of Results;

WP3: Robust Fractional Order Control Strategies for Distributed Control Systems;

WP4: Bio-inspired Fault-tolerant Control System Architecture Development for Distributed Systems;

WP5: Case study: the cryogenic carbon isotope separation columns cascade control system.

Activities

WP1: Project Management

Activity 1.1: Overall management of the project,

Activity 1.2: Preparation of the financial and scientific report for the contracting authority

WP2: Dissemination of Results

Activity 2.1: Presentation of results in international conferences and workshops, possibly in invited sessions organized by the team members;

Activity 2.2: Preparation of journal articles and reports that will be made available to the research community;

Activity 2.3: Exchange of relevant information with research teams abroad that are working on similar problems

Activity 2.4: Creation of a project website with the permanent update of the research evolution.

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Activities

WP3: Robust Fractional Order Control Strategies for Distributed Control Systems

Activity 3.1: Simplify the existing frequency domain approach for fractional-order controller design and develop novel control strategies in the field.

Activity 3.2: Design new structures based on dead time compensation and fractional fault-tolerant, distributed robust control.

Activity 3.3: Design a software program that will provide the possibility to design robust, distributed fractional controllers for specific processes.

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Activities

WP4: Bio-inspired Fault-tolerant Control System Architecture Development for Distributed Systems

Activity 4.1: Modeling the distributed control system as a Multi Agent System (MAS);

Activity 4.2: Develop a self organizing approach of the control structure inspired from the pattern of a bacteria colony.

Activity 4.3: Implementing the Multi Agent System using proper programming languages

Activity 4.4: Testing the developed control structure system fault tolerance and robustness in different scenarios.

Activity 4.5: Design a software tool that will provide the possibility to design bio-inspired fault-tolerant, distributed controllers for specific processes.

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Activities

WP5: Case study: the cryogenic carbon isotope separation columns cascade control system

Activity 5.1: Application of the distributed control strategies developed in WP3 for the cryogenic carbon isotope separation columns cascade.

Activity 5.2: Application of the distributed control strategies developed in WP4 for the cryogenic carbon isotope separation columns cascade.

Activity 5.3: Testing and improving the developed control structure for different real case scenarios

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Milestones

- Development of novel, simplified fractional order control strategies
- Development of robust control strategies for distributed control systems
- Modeling the distributed control system as a Multi Agent System
- Development of a fault tolerant, self organizing approach of the control structure inspired from the Nature
- Application of the developed control strategy to the isotope separation columns

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Challenges

Distributed control systems involve two levels of interaction:

- the communication layer (exchanging the information between sensors, computing devices (controllers), and actuators) and
- the physical layer (capturing the interactions and dependencies between the various components of the system).

Typically, the former is assumed to be discrete-time or event-driven (e.g., packet-based routing over networks), whereas the latter is a continuous-time system.

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Challenges

Systematically overcoming faults and disturbances is a topic that is still in its infancy and remains a prohibitive factor for realizing the full potential of complex cyber-physical systems. Fault tolerance or resiliency aspects of distributed control systems need to be taken into consideration at design time and not be an after-the-fact addition to an already completed (not necessarily fault-tolerant) design.

Results

The ***final result*** of the project will be a complete control solution for a fault tolerant, bio-inspired robust control of cyber-physical systems

The ***main results*** can be summarized as follows:

1. A detailed analysis of novel theories that combines fault tolerant, bio-inspired and robust control;
2. A case study involving the control of a cryogenic carbon isotope separation columns cascade;
3. New control structures suitable for cyber-physical systems;
4. A new software algorithm that would allow engineers to tune the controller according to specific process characteristics.

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Next steps

- Implement different self-organizing approaches
- Extend the designed control structures for a wide range of complex systems, choosing the most suitable self-organizing approach
- Implement the control system for industrial plants

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Thank you!

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