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# Autonomous and cooperative control of interconnected systems with similar dynamics

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## 1 Introduction

The use of communication networks enables an information exchange among subsystems, which are spatially distributed but have a physically interconnection. The control performance can be improved by using the information channels to exchange appropriate data between the subsystems. If the subsystems can ensure their given restrictions, no communication is necessary and the controller of the subsystem uses only local information to generate the control input. If a subsystem state exceeds a threshold, the controllers have to cooperate in order to guarantee the required performance of the subsystem and of the overall system. Hence, the operation modes can be subdivided as follows:

- *Autonomous mode* includes a decentralized control, where the control input only depends on local information. Requirements are stability, command signal tracking and disturbance rejection (left side of Fig. 1).
- *Cooperative mode* includes a distributed control, where the control input depends on local information as well as on communicated information. In addition to the requirements of the autonomous mode, disturbance rejection and damping of disturbance propagation are necessitated (right side of Fig. 1).

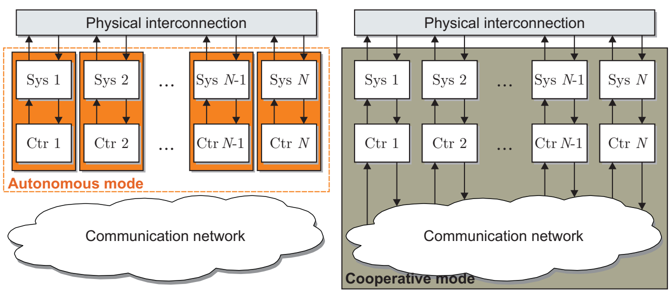


Figure 1: Control of interconnected systems in autonomous mode and cooperative mode

## 2 Project aims

The goal of this project is to extend present autonomous and cooperative control strategies for identical subsystems to subsystems with similar dynamics. The approaches [1–4] for identical subsystems will be modified to design a controller for a system with similar dynamics. The performance deviation w.r.t. the different dynamics of the subsystems will be analyzed compared to the performance with identical subsystems.

In the course of the project, answers will be given to the following questions:

- How does the performance of the controller change with similar subsystems?
- Which restrictions have to be made for the similarity of the subsystems?
- How do the switching event times and the communication time intervals change?

## 3 Systems with similar dynamics

### 3.1 Decomposition

The original system that consists of $N$ subsystems with similar dynamics should be disassembled into $N$ identical subsystems, each of which has an error model (EM), see Fig 2. The identical subsystems are defined by a nominal model (NM) that has to be determined by analyzing the original system and, if applicable, has to be changed after the control design and the analysis of the control performance for the similar subsystems. The set of all identical subsystems and their physical interconnections constitute the core of the decomposed system. The error model describes the difference between the nominal model and the corresponding similar subsystem.

The decomposed physically interconnected subsystems are described by the linear state-space model of the core

$$\begin{aligned}
\dot{\boldsymbol{x}}_i(t) &= \boldsymbol{A}\boldsymbol{x}_i(t) + \boldsymbol{B}\boldsymbol{u}_i(t) + \boldsymbol{E}\boldsymbol{s}_i(t) + \boldsymbol{P}\boldsymbol{f}_i(t), \quad \boldsymbol{x}_i(0) = \boldsymbol{x}_{i0}\\
\boldsymbol{y}_i(t) &= \boldsymbol{C}\boldsymbol{x}_i(t) + \boldsymbol{H}\boldsymbol{f}_i(t)\\
\boldsymbol{z}_i(t) &= \boldsymbol{C}_{\mathrm{z}}\boldsymbol{x}_i(t) + \boldsymbol{H}_{\mathrm{z}}\boldsymbol{f}_i(t)\\
\boldsymbol{s}_i(t) &= \sum_{j=1}^{N} \boldsymbol{L}_{ij}\boldsymbol{z}_j(t)\\
\boldsymbol{v}_i(t) &= \boldsymbol{C}_{\mathrm{v}}\boldsymbol{x}_i(t) + \boldsymbol{D}_{\mathrm{v}}\boldsymbol{u}_i(t) + \boldsymbol{F}_{\mathrm{v}}\boldsymbol{s}_i(t)
\end{aligned}$$

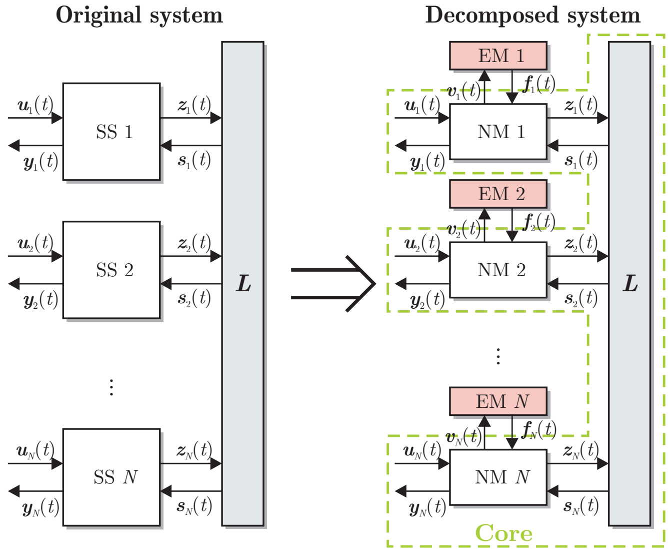


Figure 2: Decomposition of similar subsystems in a core of identical subsystems and error models

and the I/O-behavior of the error model

$$\boldsymbol{f}_i(t) = \boldsymbol{G}_{\mathrm{e}i} * \boldsymbol{v}_i(t),$$

where the matrix $\boldsymbol{L}_{ij}$ specifies the impact of subsystem $j$ on subsystem $i$.

## 3.2 Controller design

There exist several strategies to design autonomous and cooperative controllers for identical subsystems [1–4]. In [1], a decomposition approach by performing a state transformation allows the design of a stabilizing decentralized controller by considering a single subsystem. For this, special structural properties of the physical interconnection are considered. These existing strategies can be used to design a controller for the core of the decomposed system. The design have to be analyzed afterwards for the decomposed subsystem with the error models and the original system, respectively.

## 3.3 Analysis of the controller

The error model is assumed to be exactly known but is described by an upper bound

$$\bar{\boldsymbol{G}}_{\mathrm{e}i}(t) \geq |\boldsymbol{G}_{\mathrm{e}i}(t)| \qquad \text{for all } t.$$

Hence, the output $\boldsymbol{f}_i$ of the error model is also bounded

$$|\boldsymbol{f}_i(t)| \leq \bar{\boldsymbol{G}}_{\mathrm{e}i} * |\boldsymbol{v}_i(t)|\,,$$

if a bounded input $\boldsymbol{v}_i$ is given. By using an upper bound for the error model, estimations for the control performance of the designed controller can be given. At first, a proof of stability has to be conducted. Than, the compliance of the set bounds for the controlled variables, switching event times and communication time intervals has to be investigated. If the results of the analysis are not satisfactory, the decomposition, the design of the controller or both need to be adapted.

# 4 Application

A multizone furnace, presented in Fig. 3, is used to grow GaAs crystals with the highest possible purity. It consists of a large number of similar heating zones, which have separate sensing and actuating units so that they can be controlled independently. Firstly, the crystal in the middle of the furnace is heated up above the melting point. Then, it is cooled down in a coordinated way, e. g. from left to right, so that foreign substances will float to the end of the crystal.

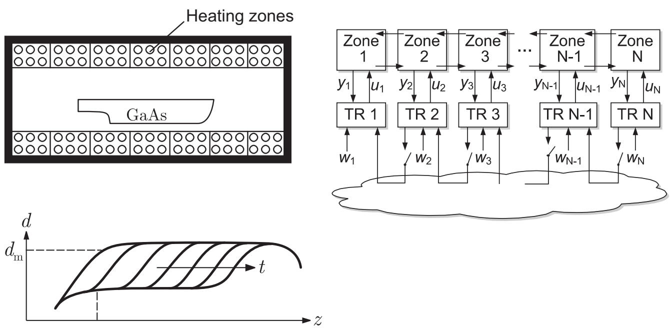


Figure 3: Multizone crystal growth furnace

The heating zones are physically interconnected and cannot be seen as separate subsystems because of the heat transfer between the neighboring zones. The strength of the coupling depends on the temperature difference. While heating up, the heating zones are weakly coupled since the temperature difference is small. The system is in autonomous mode and the subsystems can be controlled with decentralized controllers. While cooling down, the heating zones are strongly coupled, since the temperature difference between neighboring zones grows. The system is in cooperative mode. An information exchange between the heating zones is necessary to consider their physical interconnection while generating the control input such that the desired temperature gradient (shown in the bottom of the Fig. 3) is achieved.
The size of the heating zones varies due to the need for different fine temperature transitions in certain areas of the furnace. Thus, the subsystems (heating zones) are not identical but have a similar dynamic. Hence, the difference of subsystems have to be taken into account while designing the controller.

# References

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