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Selection of Decentralised Control Structures: Structural Methodologies and Diagnostics

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Abstract: The paper aims at formulating an integrated approach for the selection of decentralized control structures using a number of structural criteria aiming at facilitating the design of decentralised control schemes. This requires the selection of decentralisation structure that will allow the generic solvability of a variety of decentralised control problems, such as pole assignment by decentralised output feedback. The approach is based on the use of necessary and sufficient conditions for generic solvability and exact solvability of decentralised control problems. The generic solvability conditions lead to characterisations of inputs and outputs channel partitions. The exact solvability conditions use criteria on avoiding the presence of fixed modes, as well as necessary conditions for pole assignment, expressed in terms of properties of Plücker invariants and Markov type matrices. The structural approach provides a classification of desirable input and output partitions based on structural criteria and it is embedded in an overall framework that may involve aspects related to large scale design.

Keywords: Linear multivariable systems; output feedback control; structural methods; decentralised control; algebraic methods; geometric methods.

1. INTRODUCTION

The selection of a decentralisation scheme is a problem that has not been properly addressed as a design issue and has been handled mostly using process dependent heuristics, conditions derived from the nature and spatial arrangement of sub-process units and the criteria, diagnostics of the interaction analysis. This problem is within the area of control structure selection, or Systems Instrumentation (Karcanias, 1996) and involves steps such as: classification of variables of the model into inputs, outputs and internal variables (Karcanias, 1996); definition of effective sets of inputs, outputs (Karcanias and Vafiadis, 2002); and finally the selection of the feedback coupling of the Control Scheme (Morari and Stephanopoulos, 1980), (Siljak, 1991), (Abdolmaleki et al., 2014) etc). These families of problems may be considered within the framework of structural methodologies for linear systems and each one of them involves concrete sub-problems. The design of decentralisation schemes is a problem which may be studied using criteria based on the nature of the process (Morari and Stephanopoulos, 1980), geographical location of subsystems, graph based structural analysis (Siljak, 1991), interaction indicators (Ahmadi and Aldeen, 2013), (Grosdidier and Morari, 1986), and general coupling diagnostics based on generic properties and invariant based criteria. We address the problem of design of decentralisation schemes in order to guarantee, or well condition the solvability of families of control problems. As such the overall approach is based on the philosophy of defining schemes which exclude undesirable characteristics, such as fixed modes. Deriving a systematic methodology for synthesis of decentralisation schemes requires an approach that involves: (a) Classification of variables, definition of system progenitor models and definition of effective sets of inputs, outputs (Karcanias and Vafiadis, 2002) (b) Handling large scale issues using decomposition methodologies (Morari and Stephanopoulos, 1980) and graph methodologies (Abdolmaleki et al., 2014) (Siljak, 1991); (c) Developing structural methodologies preconditioning the solvability of control theoretic problems (Karcanias and Leventides, 2005), (Lampakis and Karcanias, 1995); (e) Design indicators and optimization based methodologies enabling the solvability of a number of decentralized control problems (Manousiouthakis et al., 1986). Such an integrated methodology is currently missing and an early form has been introduced in (Karcanias et al., 1997).

The problem considered here is the reverse of the standard decentralised control problem. The standard problem assumes a given decentralised structure and then examines the solvability of various types of control problems. In our approach the reverse problem is considered, where the selection of decentralised structures is a design problem and we use structural properties for the evaluation of

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control structures which precondition solvability of control assignment problems. The overall framework developed aims to contribute in answering questions such as selecting between centralised versus decentralised, and if decentralised, then specify the exact nature of decentralisation that involves the partitioning and pairing for the particular channels.

This paper considers the development of the structural methods for the selection of decentralisation. An integral part of the structural methodologies is the distinction between generic solvability conditions and parametric invariant dependent conditions, where the model parameter play an important role. Results on decentralised control which provide necessary conditions for solvability of control problems (Anderson and Clements, 1981), (Karcanias et al., 1988), (Siljak, 1991), (Wang, 1994), (Leventides and Karcanias, 1995) provide the basis for the current study. Specifically here we focus on solutions of static and dynamic assignment problems.

The structural approach is based on existing generic solvability conditions and on the Exterior Algebra model based diagnostics (Karcanias and Giannakopoulos, 1984), (Karcanias et al., 1988), (Leventides and Karcanias, 1998b) involving Plücker matrices, decentralized Markov parameters and criteria for avoiding fixed modes depending on parameter model based properties. Such criteria provide the means to characterise the different features of system structure that permit, or prohibit the acceptance of solutions to control problems. We will use the generic solvability conditions to develop partitions of the input and output sets characterising decentralization, which have good potential and then examine the criteria based on parametric invariants for more detailed evaluation of alternative decentralized control structures. For systems with a given number of inputs, outputs and states but otherwise unstructured models, the problem of selection of decentralisation has to do with the partitioning of inputs outputs into channels, each one characterised by its cardinality and then decide about their coupling, whether feedback control is to be used. Deciding about the nature of cardinality of the particular channel, as well as the number of desirable channels is one of the problem we are concerned with here and it is based on generic properties. The results of this investigation are used prior to the deployment of parameter dependent diagnostics and thus form part of the first screening of the options for selection of decentralisation. We will then consider the significance of the system model parameters and selected decentralization using the results of the exterior algebra framework for the study of Decentralized Determinantal Assignment Problems (Karcanias and Giannakopoulos, 1984; Karcanias et al., 1988). We aim to eliminate the existence of fixed modes and guarantee full rank properties to the decentralised Plücker matrices. The paper presents aspects of structural methodologies for design of decentralisation schemes, which are part of an overall integrated philosophy for design of such schemes.

2. OVERALL APPROACH FOR THE SELECTION OF THE DECENTRALISATION STRUCTURE

The selection of the decentralisation structure involves answering questions on whether we have to use centralised, or decentralised schemes; if decentralisation is needed, then we need to decide on the partitioning of the input, output channels, as well as the way we have to couple them in a feedback configuration. An integral part of the design is also the specification of the required order of dynamics of the selected decentralised scheme. Here, however, we will focus on constant feedback design. Our approach for the selection of the decentralisation involves a number of general steps which will be considered in this section.

Step 1. Use knowledge on the process, geographical location of process units and operational requirements, such as the nature of optimisation problem, to define a first appraisal of options as for centralisation versus decentralisation. If decentralisation is needed, then the physical arguments lead to the first structuring of the decentralisation scheme, referred to as feasible decentralisation.

This step aims to take into account the particulars of the application area and nature of the problem. This knowledge is essential and it is part of the overall problem specification. What is expected at this stage is the development of the first structuring of the schemes in terms of super-blocks, which themselves may require some further structuring subsequently. This area of work may be considered as a part of the control structure selection on the entire plant.

Step 2. Use of graph analysis methodology to develop system decompositions (Siljak, 1991), which may indicate structuring of the decentralisation and also use of the concept of structural fixed modes for evaluation of alternatives.

For systems which have an explicit graph structure, a procedure leading to overall system decomposition, may be used in developing further the possible structures specified in step (1) and then evaluating alternatives based on the exclusion of structural fixed modes based on properties of the system graph.

Step 3. Use results on the generic solvability of decentralised control problems to produce a parameterisation of alternatives.

The study of decentralised control problems has produced some results characterising generic solvability of control problems (Anderson and Clements, 1981), (Karcanias et al., 1988), (Siljak, 1991), (Wang, 1994), (Leventides and Karcanias, 1995) which can lead to parameterisation of possible partitions of input, output channels which permit solvability of control problems. These results depend on structural characteristics such as the McMillan degree and the numbers of inputs, outputs.

Step 4. Use results on the solvability of decentralised control problems based on parameter dependent structural invariants to produce a parameterisation of alternatives based on diagnostics for solvability of decentralised control problems.

At this stage we proceed with the evaluation of the available options using linear models and parameter dependent properties such as fixed modes, almost fixed modes (Karcanias et al., 1988), properties of the rank of decentralised Plücker matrices, strong instability and minimum phase phenomena. Tests based on exterior algebra diagnostics