CONTROL THEORY ISSUES AND PROBLEMS IN GLOBAL INSTRUMENTATION

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ABSTRACT

The instrumentation of a process, selection of measurement variables (outputs), and actuation variables (inputs) has a "micro" (local), as well as a "macro" (global aspect. The "micro" role of instrumentation has been well developed and deals with the problem of measurement, or implementation of action upon given physical variables; instrumentation theory and practice deals almost exclusively with the latter problems. The "macro" aspects of instrumentation stem from that designing an instrumentation scheme for a given process (classification and selection of input and output variables) expresses the attempt of the "observer" (designer) to build bridges with the "internal mechanism" of the process in order to observer it and/or act upon it. What is considered as the final system, on which Control System Design is to be performed, is the object obtained by the interaction of the "internal mechanism" and the specification of the overall instrumentation scheme. Difficulties in control of the final system may be assessed in terms of certain structural characteristics of the final system model. These structural characteristics are formed through the various stages, where the design goes through. The aim of this paper is to examine a number of problems associated with the selection of input, output schemes of a process and in particular to investigate the relationship between these problems and the effect on the resulting system structure.

The general types of problems related to the selection of input, output schemes for a process may be classified as [1]:

(i) Model Orientation Problems (MOP)
(ii) Model Expansion Problems (MEP)
(iii) Model Projection Problems (MPP)

The first deals with the classification of internal variables into inputs, outputs, whereas the second refers to the family of problems which deal with the selection of additional measurements for reconstruction of unmeasurable internal variables. The problems

considered here are those referred to as the Model Orientation and Model Projection problems and they are considered below:

The classification of system variables as inputs and outputs is referred to as model orientation. In many systems, the orientation is not known, or that depending on the use of the system the orientation changes. A theory of linear systems, where the orientation is not considered as an issue and which is based on system behaviour have been developed by Willems, [2], [3] and uses the implicit system descriptions [4], [5]. In this paper we consider linear description of the type

$$\tilde{S}(F,G): F\,\dot{\underline{z}} = G\,\underline{z},\ F,\ G \in \mathbb{R}^{pxk} \tag{1}$$

where $\underline{z}$ is the vector of internal variables; this description is considered as a progenitor description for all regular or singular descriptions S(E,A,B,C) obtained from $\tilde{S}(F,G)$ by assigning some orientation to the variables in $\underline{z}$. Questions such as, when is a set of variables implied, or not anticipated by another, or when is it free are considered first and then the general relationships between the Kronecker invariants of $\tilde{S}(F,G)$ and the feedback Kronecker structure of the different S(E,A,B,C) systems is considered. Conditions for the oriented models to be proper and have certain desirable characteristics are derived and links between the Kronecker structure of S(F,G) and the McMillan degree of the oriented input-output models are established.

It is assumed now that issues related to model orientation have been resolved and that the process is represented by a Linear Time Invariant model, which also is assumed to be Finite Dimensional. If V, Z denote the spaces of <u>all</u> potential inputs, measurements, referred to as extended input, output spaces and $\underline{v}$, $\underline{z}$ are the corresponding p, q-dimensional vectors, then the system is represented by the qxp transfer function matrix F(s) and

$$\underline{z}(s) = F(s)\,\underline{v}(s),\ F(s) \in \mathbb{R}^{qxp}(s) \tag{2}$$

This model is called the <u>Process Progenitor Model</u> (PPM) and according to the degree of modelling (assumed complexity and accuracy) represents the knowledge we have about the system. In an ideal design, unconstrained by resources and effort all possible inputs and outputs should be used; economic and technical reasons, however force us frequently to select a subset of the potential inputs, outputs as effective, operational inputs, outputs. Engineering specifications and past experience with similar designs, provide some guidance in how to select the effective l-inputs and effective m-outputs; however, they do not specify a solution uniquely. Developing criteria and techniques for selection of an effective input output scheme as projections of the extended input, output vectors respectively is what we call <u>Model Projection Problems</u> (MPP). Under the present assumptions of the PPM, the MPP is equivalent to selecting the sensor, actuator maps, matrices respectively H(s), $\in \mathbb{R}^{pxl}(s)$, G(S)$\in \mathbb{R}^{mxq}(s)$, ($\leq$q, 1 $\leq$p) such that the <u>Process Effective Model</u> (PEM) with $\underline{y}$ outputs and $\underline{u}$ inputs is described by:

$$\underline{y}(s) = H(s)\,\underline{z}(s),\ v(s) = G(s)\,y(s) \tag{3a}$$

$$\underline{y}(s) = W(s)\, \underline{u}(s),\ w(s) = H(s)\, F(s)\, G(s) \tag{3b}$$

and has a transfer function matrix W(s) with certain desirable properties. Note that the G(s), H(s) matrices are not completely free, but their structure is constrained; furthermore, their dynamics express those of the actuators, sensors used. In this paper we shall assumed both H(s), G(s) constant and unconstrained and thus the problem becomes simpler and it is referred to as Constant MPP(CMPP).

There are different issues and objectives which may be defined as part of MPP. In this paper we examine CMPP and the criteria in the selection of (H,G) instrumentation pairs are those defined by the control properties of the resulting mode. Some of the specific problems addressed here are:

(i) Examine the effect of selection on the number of effective inputs, outputs on the generic structural characteristics of the resulting model and determine the lowest bounds for these numbers which are needed to guarantee certain structural control properties, or solvability of families of control problems.

(ii) Investigate the effect of the structure selection of (H, G) maps from the structural controllability, observability viewpoint, as well as formation of other structure characteristics of the resulting model.

(iii) Study the effect of the selection of a fixed structure pair (H, G) on the numerical dependent resulting model characteristics such as multivariable zeros etc.

The above list of problems is by no means complete. These problems have not been addressed properly before, with the exception of those problems referred to as "zero assignment" [6], [7], [8], [9] which belong to the (iii) class of problems above. The tools for answering the questions in the (i) class are provided by Control Theory concepts and results [10], [11], whereas those in the (ii) category come from the structural, graph approach [12], [13]. The above problems have been motivated by the need to develop tools for an integrated approach to Process and Control Design (ESPRIT II EPIC) [14]. The present paper aims at providing a clear formulation of the framework of these problems from the Control Theory viewpoint, discuss useful tools and techniques, essential for theory study, and finally given solution to a number of them.

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