Control of MIMO systems with multiple delays

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Abstract— **This presentation deals with the control of multiple-input-multiple-output linear multi time-delayed systems. The process can be disturbed and unstable. A new control structure is proposed, solving the problem in several steps. First, a stable predictor/observer for an internal non-delayed signal is designed. This predictor is always stable, regardless the possible instability of the plant. Then, the plant is stabilized, regardless the delays. The procedure involves canceling the interactions by means of disturbance observers. The approach is general and it can be applied to unstable plants.**

I. INTRODUCTION

Most practical processes involve the presence of time delays. Their presence in a feedback control loop makes difficult a good process operation. Except for seldom situations where they can be beneficial [1], their effect is performance degrading.

A time delay in the loop prevents high gain controller from being used, leading to offset and sluggish system response. A control system is designed to achieve some given controlled plant performance. As the delay is unavoidable, the purpose of the control should be to modify the dynamic behavior of the rest. Thence, the control should only deal with the process part whose dynamic should be controlled, keeping unchanged the rest of the system. No feedback control law can reduce the delay.

Even in most cases the delays appear in continuous time, leading to non-rational transfer function based models, the implementation of any control solution should be based on the use of a computer, thence, requiring a discrete time representation. Time delays, in discrete time, are represented by delay operators. Thus, if the delay is short (a small multiple of the sampling period) it can be treated as an augmented state vector, simplifying extraordinarily the control design problem. But for long delays, the state augmentation approach becomes very complicated and new solutions have been proposed.

Other than the well known Smith Predictor (SP) approach [2],[3], applicable for continuous and discrete plants, discrete time delay compensators can be used to control unstable and non-minimum phase plants, [4].

On the other hand, to counteract the effect of disturbances, a Disturbance Observer (DOB) following the ideas of [5], can be designed. In a MIMO system, the interactions or cross-effect between inputs can be considered as disturbances, being counteracted by the use of a DOB.

To deal with multi-delayed MIMO processes the following strategy is proposed. First, based on a stable predictor, an internal non-delayed signal is estimated. This computed output is then used to estimate the system state and to design any stabilizer controller.

On the stabilized plant, a DOB is designed to compensate the effect of additional inputs in each input/output pair.

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II. MAIN RESULTS

Let us consider the SP control schema, figure 1.

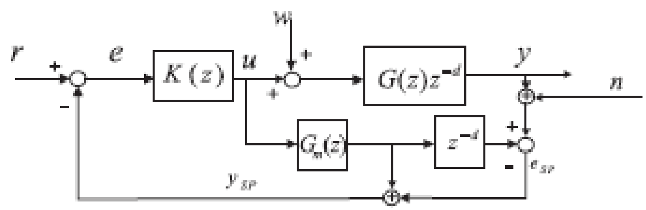

Fig.1 Smith Predictor

Initially developed for SISO stable plants, it can be modified to deal with unstable plants and MIMO, if the transfer matrix can be decomposed into the product of two matrices: one fast undelayed term and a diagonal matrix of delays. This can be only achieved if all the input delays are the same.

In [6], a generalized predictor is introduced. It can be easily extended to MIMO plants [7], figure 2, and it can be applied to long delay systems [8].

Let us consider a plant given by

$$P(z) = \begin{bmatrix} p_{11}(z) & \cdots & p_{1m}(z) \\ \vdots & \ddots & \vdots \\ p_{m1}(z) & \cdots & p_{mm}(z) \end{bmatrix}$$

Where: $p_{ij}(z) = g_{ij}(z) z^{-d_{ij}}$.

Assuming an internal representation

$$G(z) = C(zI - A)^{-1}B = \begin{bmatrix} c_1 \\ \vdots \\ c_m \end{bmatrix} (zI - A)^{-1} \begin{bmatrix} b_1 & \cdots & b_m \end{bmatrix}$$

Define the filter matrix:

$$\Psi(z) \doteq \begin{bmatrix} \psi_{11}(z) & \cdots & \psi_{1m}(z) \\ \vdots & \ddots & \vdots \\ \psi_{m1}(z) & \cdots & \psi_{mm}(z) \end{bmatrix}$$

$$\psi_{ij}(z) = c_i A^{-d_{ij}} \sum_{k=1}^{d_{ij}} A^{k-1} b_j z^{-k}$$

where .

The following predictor is derived, figure 2.

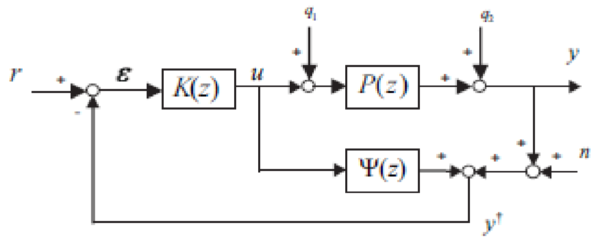

Fig.2 Generalized Predictor

The main advantage is that the filter □(z) is always stable. It can be derived that $\Psi(z) + P(z)$ is an undelayed transfer matrix, so the controller $K(z)$ can be designed for a delay-free MIMO plant. This controller can be designed to stabilize the unstable initial plant or to assign the closed-loop system dynamics by using a state estimator and a state feedback law.

The last issue, related to system interactions, can be solved by applying the concept of the DOB. It is summarized in figure 3.

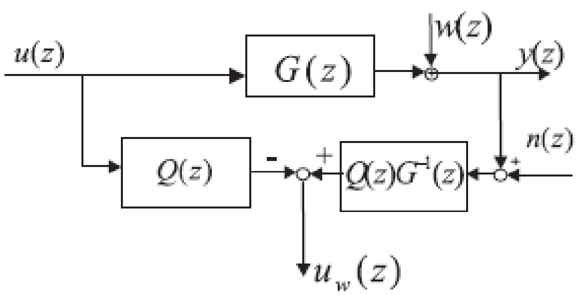

Fig.3 Disturbance Observer

Assuming an output disturbance $w(z)$, the structure in this figure allows to estimate the signal $G^{-1}w$. Thence, if this signal is subtracted at the input, the disturbance will be cancelled. An appropriate selection of the key design parameter $Q(z)$, will permit the filters to be realizable and to reduce the noise and the disturbance.

In the case of the original problem, a MIMO multidelay system, once an appropriate input/output pairing has been done, for each output the remaining outputs are considered as disturbances, as depicted in figure 4.

Some examples illustrate the procedure and will point out the advantages and inconveniences of this approach.

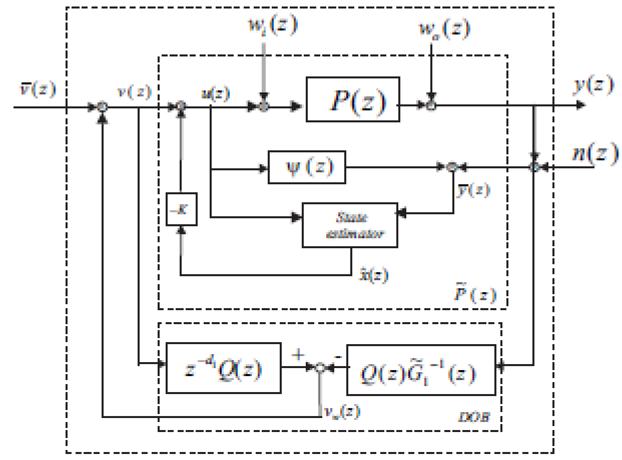

Fig. 4. General control structure

III. BIOGRAPHY

Pedro Albertos, past president of IFAC (the International Federation of Automatic Control) in 1999-2002, is a world recognized expert in embedded systems and real-time control, leading several projects in the field. Full Professor since 1975, he is currently at Systems Engineering and Control Dept. UPV, Spain. He is Doctor Honoris-Causa from Oulu University (Finland) and Bucharest Polytechnic (Rumania). Invited Professor in more than 20 Universities, he delivered seminars in more than 30 universities and research centers. Authored over 300 papers, book chapters and congress communications, co-editor of 7 books and co-author of "Multivariable Control Systems" (Springer 2004) and "Feedback and Control for Everyone" (Springer 2010), he is also associated editor of Control Engineering Practice and Automatica and Editor in Chief of the Spanish journal RIAI. His research interest includes multivariable control and non-conventional sampling control systems, with focus on time delays and multirate sampling patterns.

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