Research Article

GMC ALGORITHM WITH IMC AND OTHER CONTROLLERS FOR A CHEMICAL PROCESS

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ABSTRACT
This article presents Generic Model Control (GMC) algorithms for a approximated model of interacting thermal process. Control laws obtained are relatively simple with good results. The algorithm makes the closed loop system linear in an input-output sense. Simulation results are verified. A MIMO process with IMC and PI, PI with set point weighting, Fuzzy Logic Controller was designed and implemented and their responses compared.

KEYWORD GMC controller, MIMO, Interaction.

INTRODUCTION
Conventional process control system mostly utilizes linear dynamic models. But most of the chemical processes possess non-linear dynamic characteristics. The traditional approach to design controllers for a non-linear process is to linearize the process model around its steady state operating point and to apply the linear control theory to it. However when the process moves away from the steady state around which the controller was designed, the characteristic of the process may vary from that of predicted one. Lot of work has been recently carried out on decoupling and linearization based on non-linear feedback transformation for non-linear control systems. However this control theory is developed under the assumption that the process model is known exactly. Therefore if there is a difference between this real process and the process model, application of this theory will give unsatisfactory results. The degree of the mismatch is not high in many chemical processes. In such cases, it is sufficient to add external controllers which compensate for the mismatch. Kravaris and Soroush proposed a control strategy which is called the multi input/multi output (MIMO) globally linearizing control. For SISO systems, input output linearization is done and explicit formulas for linearizing state feed back can be obtained. Then this state feedback law is applied to a nonlinear process and an external controller with integral action can be used for set point tracking and rejection of disturbances. The resulting control structure is called the globally linearizing control (GLC) structure. This methodology is tried here for a MIMO nonlinear system having equal number of inputs and outputs. The non-linear system is defined as

\[ x = f(x) + g(x)u \]  
\[ y = h(x) \]

where \( x \) is the state vector of dimension \( n \), \( u \) is an input vector of dimension \( m \), \( y \) is an output vector of dimension \( p \), \( f(x) \) is a smooth function, \( h(x) \) is a \((p,1)\) vector with a row element \( h_j(x) \) also a smooth function and \( g(x) \) is an \((n,m)\) matrix with elements of each column being \( g_j(x) \).

Complex processes often have several variables (outputs) that we wish to control, and several manipulated inputs to provide the control. Consider a plant with \( m \) output variables \( y_1, y_2, \ldots, y_m \) and \( m \) control variables, \( u_1, u_2, \ldots, u_m \). A mathematical model of this system is therefore an \( m \times m \) transfer function matrix as defined below.

\[ Y(s) = G(s)U(s) \]

or

\[
\begin{bmatrix}
Y_1(s) \\
Y_2(s) \\
\vdots \\
Y_m(s)
\end{bmatrix}
= \begin{bmatrix}
G_{11}(s) & G_{12}(s) & \cdots & G_{1m}(s) \\
G_{21}(s) & G_{22}(s) & \cdots & G_{2m}(s) \\
\vdots & \vdots & \ddots & \vdots \\
G_{m1}(s) & G_{m2}(s) & \cdots & G_{mm}(s)
\end{bmatrix}
\begin{bmatrix}
U_1(s) \\
U_2(s) \\
\vdots \\
U_m(s)
\end{bmatrix}
\]

an important general property of such systems is interaction (or coupling) between inputs \( U_i \) and outputs \( Y_j \) in the sense that any input \( U_i \), \( 1 \leq i \leq m \), will have a dynamic effect on all the outputs \( Y_j \), \( 1 \leq j \leq m \). If each input is \( U_i \) has a dynamic effect only on \( Y_i \), the system is said to be non-interacting (or decoupled).

A multivariable nonlinear system of the form of equation (1) is called input / output linearizable. If a system gets input / output linearized by state feedback in the sense of the above definition, it may be convenient to think of the closed loop system in the laplace domain. In a well formulated control problem all outputs \( y_i \) must possess relative order, so that the system is output controllable. From C. Kravaris and M. Soroush the necessary condition for input/output linearizability is, all outputs must have relative orders. Also the sufficient condition for input/output linearizability is that the system possess relative orders and characteristic matrix be nonsingular. To be able to characterize the class of input/output
linearizable systems, we need conditions which are both necessary and sufficient.

**Development of GMC control law:**

In order to calculate a control law that induces linear input/ output behavior in the MIMO system GMC algorithm is tried. It helps to find a differential operator such that, when applied to the outputs, it will provide a set of algebraic expressions in u and y that are solvable for u. The control law allows controlling linear systems without having to impose any structural constraints on the closed-loop dynamics of the system. The objective is to find a control law such that y is equal to Ysp. According to GMC formulation as

\[
\begin{bmatrix}
    y_1
    \\
    y_2
\end{bmatrix} = \begin{bmatrix}
    k_{11} & 0
    \\
    0 & k_{12}
\end{bmatrix} \begin{bmatrix}
    y_{up} - y_1
    \\
    y_{up} - y_2
\end{bmatrix} + \int \begin{bmatrix}
    k_{21}
    \\
    0
\end{bmatrix} \begin{bmatrix}
    y_{lp} - y_1
    \\
    y_{lp} - y_2
\end{bmatrix} dt
\]

The value of \(k_{11}\) and \(k_{12}\) and \(k_{21}\) and \(k_{22}\) can be selected to achieve a desired process response. The standard GMC design approach is limited to a nonlinear process with relative degree one. For process with relative degree Rd>1, then the selection of GMC parameters becomes more complicated. Further since the GMC design method is a special case of feedback linearizing controller, Fig 1 shows a block diagram of the closed loop system using the GMC controller.

**Application to Chemical Process Control**

Level and Temperature Control Process

This process is shown schematically in Fig 2, adapting parameters from the reference paper [2][1]. Simulations are carried out and closed loop response obtained.

**Internal Model Controller Design:**

The simple structure and robustness to modeling error of the internal model-based control (IMC) technique, characterized by the block diagram in Fig. 3, make IMC a viable alternative to PID control. Especially for processes with significant dead time, a much improved performance of IMC control over PID control can be obtained. A multiple-output IMC (also known as coordinated control) provides flexibility in the control of multivariable processes, for example, achieving the fastest response to a change in setpoint (SP) or disturbance. The same IMC approach has been extended to multiple-input multiple-output (MIMO) processes. In the IMC approach as represented in Fig. 3, a mathematical model of the process is used to calculate (predict) future process variable (PV).

\[
U_1 = SV_1 + Kx_1^{1/2}
\]

\[
U_2 = C_SsX \left\{ V_2 \left( \frac{T_3 - x_2}{x_1} \right) V_1 - \left( \frac{T_0 - x_2}{sX} \right) K_x^{1/2} \right\}
\]
where $G_p(s)$ is the process transfer function and $G_m(s)$ is the model of the process. $G_m(s)$ is the invertible portion of the model, i.e., $G_m(s) = G_p(s)$ with the non-invertible components such as deadtime and right half-plane zeros removed. The filter serves two purposes: (a) it is designed to ensure that the $G_c(s)$ is realizable and (b) that a desired closed-loop response for $PV(s)$ is achieved. By simple block diagram manipulations, Fig. 3 is transformed to Fig. 4 and in turn to Fig. 5.

**Simulation results and discussion**

Using the given model as taken from ref (1), and GMC algorithm with controller was designed. Simulation was carried out for various controller action. At first the simulations were done without decoupling, then PI controller was added to examine the influence of the modeling errors. Fig 6 shows the output response of the level and temperature when the set point of the level and temperature were changed from 1 to 20cm and 1 to 10°C respectively. When sudden disturbance was introduced at time of 200sec in level, it was affecting the temperature process due to interaction.

Next applying GMC algorithm with external PI controller\(^8\) was added as shown in fig 7. The sudden disturbance introduced at time of 200sec in level was not affecting the temperature process. It can be seen from the figure that the ISE is improved than in Fig 6.

Simulation after applying GMC algorithm with IMC controller is shown in fig 10a and 10b. It can be seen from the figure that under the influence of the controller performance, ISE is improved than in fig 9. Disturbance introduced in level was not affecting the temperature process.
Fig. 10 a. Output response for the level with decoupling with IMC.

Fig. 10 b. Output response for the temperature with decoupling with IMC.

CONCLUSION
The GMC algorithm was applied to a non-linear MIMO chemical process. The simulation experiments showed that even if the processes are non-linear and interactive and modeling errors are present, a satisfactory control performance could be obtained.

This paper reports the simulation application of the GMC control law to the chemical process, (level and temperature control process). Simulation approach for a multivariable process using GMC (decoupling and linearization algorithm) with PI and PI-SPW controller and FLC and IMC has been studied. Results of these simulations are presented.

REFERENCES