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Adaptive Generalized Minimum Variance (AGMV) Applied to a Heating Central

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ABSTRACT: In this paper, the Adaptive Generalized Minimum Variance (AGMVC) is designed to control a Single Input Single Output (SISO) of central heating process by adjusting the flow of hot fluid through a valve driven by an electric voltage input. The model of the process has been obtained by an on- line algorithm identification using the Recursive Least-Squares estimation technique (RLS).

KEYWORDS: Adaptive Control; minimum variance; lest-square estimation.

1 INTRODUCTION

Central heating systems [1] is necessary for heating buildings processes, and production of most consumer and manufacturing products, including those made out of combustible gas, plastic, metal, rubber, concrete, glass, and ceramics. The performance of a process heating system is determined by its ability to reach a certain product quality under constraints thresholds (for example, high temperature, and low response time). The energy efficiency of a process heating system is determined by the costs attributable to the heating system per unit produced.

So the use of advanced control methods is vital in Process heating.in this sense of optimizing the energy of control, Central heating control industry, as a general rule, has favored the pattern recognition class of adaptive controllers. Major process control manufacturers have introduced various types of auto-tuners in the last few years,

This paper presents the application of an Adaptive Generalized Minimum Variance control (AGMVC) by an adjustment mechanism which monitors the system and tunes the coefficients of the corresponding controller in order to maintain a desired performance.

And it is organized as follows. Section 2 describes the central heating control and Section 3 shows concept of generalized minimum variance control. In section 4 AGMVC system design through the Root least square identification is proposed. In section 5 a brief example is also given to show how the algorithms described here can be implemented as AGMVC. Section 6 summarizes the result this paper.

2 THE GENERALIZED MINIMUM VARIANCE FORMULATION

2.1 CONTROL ALGORITHM

Generalized Minimum Variance control (GMVC) [2] has been suggested first by Clarke, and widely applied in industry to control plant with uncertainty. And was formed basically as a modification of the Minimum Variance (MV) technique of Astrom and Wittenmark. However a brief description of the (GMVC) will be given in this section.

Consider the stochastic discrete-time linear systems described by the CARMA (Controlled Auto-Regressive Moving Average) model [3], [4], [5]:

$$A(q^{-1}).y(t) = q^{-d}B(q^{-1}).u(t) + C(q^{-1}).e(t) \tag{1}$$

Where t is the discrete time iteration and (d) is discrete dead time expressed as an integer multiple of the sampling interval Te

$y(t)$ is the output vector at time t

$u(t)$ is the control vector at time t

q^{-1} is the backward-shift operator $q^{-1}y(t+1) = y(t)$

$A(q^{-1})$, $B(q^{-1})$and $C(q^{-1})$ are polynomials in q^{-1}.

That is:

$$A(q^{-1}) = 1 + a_1q^{-1} + a_2q^{-2} + \cdots + a_{na}q^{-na} \; ; \;\; na = \deg A(q^{-1}) \tag{2}$$

$$B(q^{-1}) = 1 + b_1q^{-1} + b_2q^{-2} + \cdots + b_{nb}q^{-nb} \; ; \;\; nb = \deg B(q^{-1}) \tag{3}$$

$$C(q^{-1}) = 1 + c_1q^{-1} + c_2q^{-2} + \cdots + c_{nc}q^{-nc} \; ; \;\; nc = \deg C(q^{-1}) \tag{4}$$

d ≥1 is the time delay of the process,

$e(t)$ is a sequence of uncorrelated random zero-mean sequence with finite variance σ^2 That is,

$$E[e(t)] = 0 \quad \text{and} \quad E[e(t).e(t)^T] = \sigma^2$$

The Generalized Minimum Variance controller look for a control signal u (t) that will minimize the following criterion given as

$$J = E[\big(R.w(t) - P.y(t+k)\big)^2 + \big(Q.u(t)\big)^2] \tag{5}$$

$w(t)$ Represents the reference output signal and is assumed to be known in advance.

The objective function used to synthesize the minimum variance controller. Here, we have placed weightings on the output and set-point, and included a term to penalize excessive control effort via the use of transfer functions P, R and Q respectively.

The predicted auxiliary $\psi^*(t+d)$ output of the term in the future named $\psi(t+d) = Py\,(t+d)$, can be obtained from the following Diophantine equations:

$$P.C(q^{-1}) = E(q^{-1}).A(q^{-1}) + q^{-d}.\frac{F(q^{-1})}{P_d} \tag{6}$$

With $\deg\,(E(q^{-1}).) = d-1$ and $e_0 = 1$.

The couple (q^{-1}) , $F(q^{-1})$ always exists but it is not necessarily unique. It verifies the following relation bv using equation and equation:

$$E(q^{-1})A(q^{-1}).y(t) = q^{-d}E(q^{-1})B(q^{-1}).u(t) + C(q^{-1}).E(q^{-1})e(t) \tag{7}$$

$$[P.C(q^{-1}) - q^{-d}.\frac{F(q^{-1})}{P_d}].y(t) = q^{-d}E(q^{-1})B(q^{-1}).u(t) + C(q^{-1}).E(q^{-1})e(t) \tag{8}$$

Time shift Eq d-steps into the future by multiplying q^d to give,

$$\left[P.C(q^{-1}) - q^{-d}.\frac{F(q^{-1})}{P_d}\right].y(t+d) = E(q^{-1})B(q^{-1}).u(t) + C(q^{-1}).E(q^{-1})e(t+d) \tag{9}$$

Then,

$$P.C(q^{-1}).y(t+d) - F(q^{-1}).y(t) = E(q^{-1})B(q^{-1}).u(t) + C(q^{-1}).E(q^{-1})e(t+d) \quad (10)$$

Next, separate out terms involving future values to the right-hand-side, and terms involving past and current values to the left-hand-side:

$$\mathrm{P.C(q^{-1}).[y(t+d) - E(q^{-1}).e(t+d)] = E(q^{-1})B(q^{-1}).u(t) + \frac{F(q^{-1})}{P_d}.y(t)} \quad (11)$$

Defining then,

$$\psi^*(t+d) = \psi(t+d) - E(q^{-1}).e(t+d) \quad (12)$$

And

$$y'^{(t)} = \frac{y(t)}{P_d} \quad (13)$$

$$G(q^{-1}) = E(q^{-1}).B(q^{-1}) \quad (14)$$

We can then obtain the predicted auxiliary output $y^*(t+d)$ from the following relation:

$$C(q^{-1}).\psi^*(t+d) = G(q^{-1}).u(t) + F(q^{-1}).y'(t) \quad (15)$$

Add a $y^*(t+d)$ to equation and we have

$$C(q^{-1}).\psi^*(t+d) + \psi^*(t+d) = G(q^{-1}).u(t) + F(q^{-1}).y'(t) + \psi^*(t+d) \quad (16)$$

The d-step prediction output can be written as

$$\psi^*(t+d) = G(q^{-1}).u(t) + F(q^{-1}).y'(t) + H(q^{-1}).\psi^*(t+d-1) \quad (17)$$

Where H is another polynomial in (q^{-1}) defined as

$$H(q^{-1}) = \left(1 - C(q^{-1})\right).q \quad (18)$$

And the optimal control law can be derived from

$$\frac{\partial J}{\partial u} = 0 \quad (19)$$

Simplification and re-arrangement then gives the GMV control law as [6], [7]

$$u(t) = \frac{Rw(t) - \sum_1^{ng} g_i u(t-i) + F(q^{-1})y'(t) - H(q^{-1}).\psi^*(t+d-1) + \lambda u(t-1)}{G_0(q^{-1}) + \lambda}$$

With $Q = \lambda(1 - q^{-1})$

3 SELF-TUNING IMPLEMENTATION

The following section present a self-tuning approach for minimum variance control [8],[9] . However an adaptive controller is a set of techniques allowing adjustment of controller parameters, where the characteristics of the process and the disturbances are unknown or time varying. The recursive least square estimation is used to determine unknown parameters of the plants.

The equation () can be written as

$$\psi^*(t+d) = \varphi^T(t).\theta \quad (20)$$

With

$$\varphi^T(t) = [\varphi_1(t) \quad \varphi_1(t) \quad \dots \quad \varphi_n(t)] \quad (21)$$

And

$$\theta = [\theta_1 \ \theta_2 \ \dots \ \theta_n]^T \quad (22)$$

The recursive least-squares RLS algorithm estimate the vector of parameter θ is given by:

$$\hat{\theta}(t) = \hat{\theta}(t-1) + K(t).\left(y(t) - \varphi^T(t).\hat{\theta}(t-1)\right) \quad (23)$$

$$K(t) = \frac{P(t-1).\varphi(t)}{\mu+\varphi^T(t).P(t-1).\varphi(t)} \quad (24)$$

$$P(t) = \frac{\left(I-K(t)\varphi^T(t)\right)P(t-1)}{\mu} \quad (25)$$

μ is the forgetting factor, usually chosen as between 0.9 and 1.

At time t, vectors $\psi^*(t+d)$ appearing in the expression of $\varphi^T(t)$ with $j = d - l, \ldots, 1$ are not directly known. They could be estimated after resolution of Diophantine equations of the same type as

$$P.\hat{C}(q^{-1}) = \hat{E}(q^{-1}).A(q^{-1}) + q^{-d}.\frac{\hat{F}(q^{-1})}{P_d} \quad (26)$$

4 SIMULATIONS RESULTS

4.1 PLANT MODELING

The objective of this section is to introduce a simplified heating central system as viewing in (fig.1) and develop an AGMVC controller model. The complete system consist of a heating central, which is controlled by the flow controller FCV based on an adaptive control GMV, heat exchanger, a temperature measurement by a temperature transmitter TT, a flow valve FV and a pump for circulating the fluid through the plant.

The FCV valve is an analog valve controlled by an electric signal voltage 4-20mA.The Valve controller here is used an interfacing pneumatic 3-15psi device between the Valve and control in order to have controllable voltage that operates the valve at a desired flow.

The operating temperature of the enclosure TK2 is used as a feedback signal for the valve controller and output of the plant.

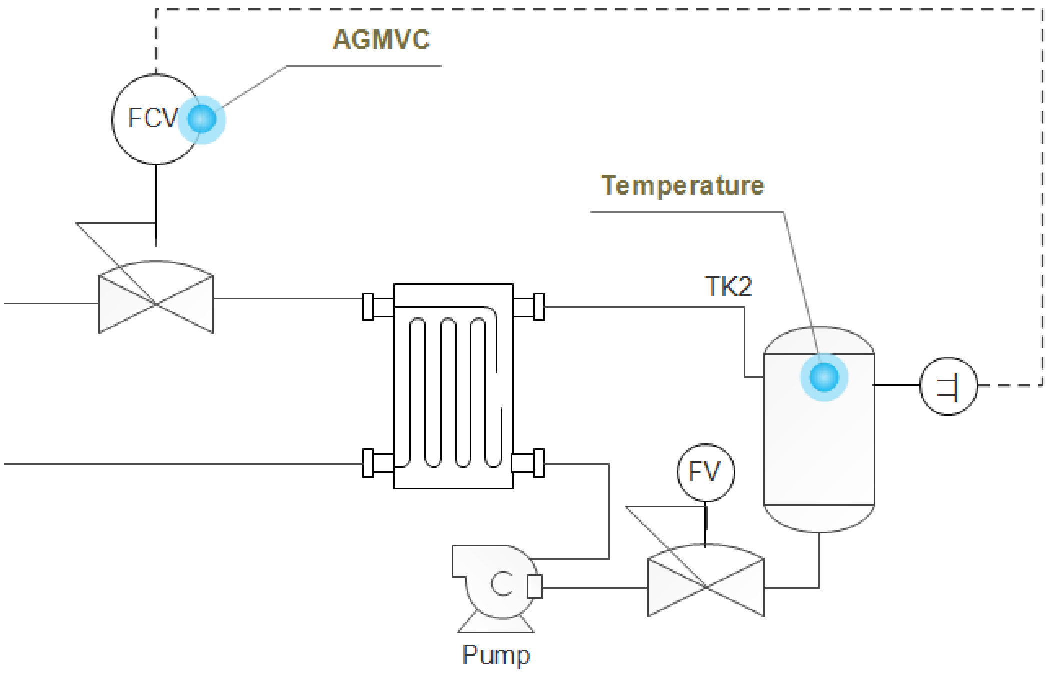

Fig. 1. Plant of heating central.

There is

$\alpha(t)$ The angle of opening of the valve,

$Q(t)$ Flow in the exchanger,

$T_1(t)$ The outlet temperature of the exchanger,

$T(t)$ The enclosure temperature

The following equations are modeling:

The law of operating the valve facing the flow in function of the angle opening

$$Q(t) = K_0 \alpha(t) \tag{27}$$

The heat transfer in the exchanger,

$$T_1(t) + \tau_1 \frac{dT_1(t)}{dt} = K_1 Q(t) \tag{28}$$

The transfer of heat in the enclosure.

$$T(t) + \tau_2 \frac{dT_1(t)}{dt} = K_2 Q(t) \tag{29}$$

The input of the system is the angle of opening of the valve $\alpha(t)$ and the output is the temperature of the enclosure $T(t)$. all initial conditions are considered zero.

The global transfer function of the system is

$$\frac{T(t)}{\alpha(t)} = \frac{K_0 K_1 K_2}{1+(\tau_1+\tau_2)s+(\tau_1\,\tau_1)s^2} \tag{30}$$

Specific design details are given for the plant in appendix in order to illustrate the approach.

Reference temperature, temperature output of the enclosure, the control voltage of the valve input and the temperature error responses are given in fig and.

The resultants figures show that the temperature response obtained using an AGMVC are faster and more efficient. The adaptive generalized minimum variance compensates the changes in source voltage resulting in a minimum effect on the temperature of enclosure.

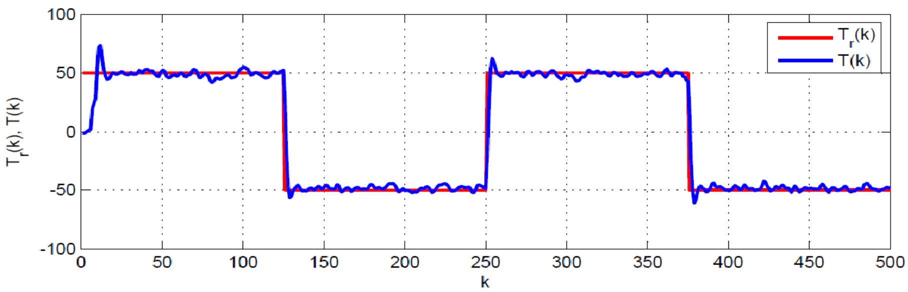

Fig. 2. Control input with noise presence conditions: AGMVC control

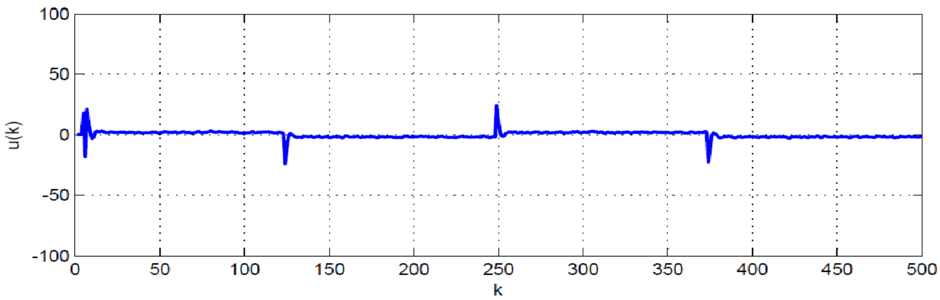

Fig. 3. Temperature output with noise presence conditions: AGMVC control

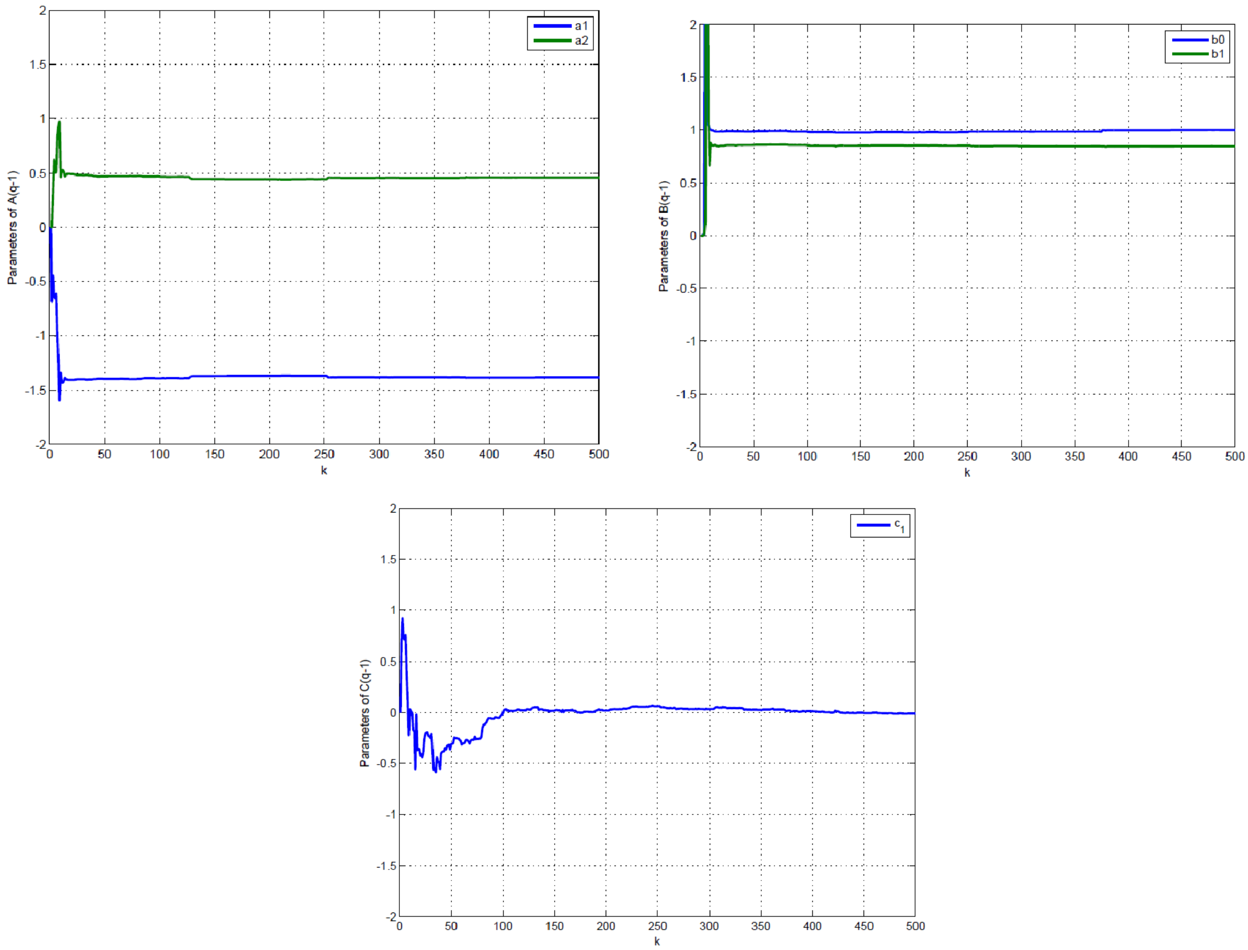

Fig. 4. Tuned parameters of system model (CARIMA)

5 CONCLUSION

In this paper, a design method of generalized minimum variance control using strong stability rate was given. The numerical example was shown to verify the validity of the proposed method. As future works, there is an extension to multi-input multi-output systems using the proposed method. Moreover model-free control system through strong stability rate will be considered

APPENDIX

Heating central parameters:

Give the following values of transfer gains and thermal time constants

$$K_0 = 10 \ ; \ K_1 = 105 \ ; \ K_2 = 14.5 \ ; \quad \tau_1 = 5\,\mathrm{s} \ ; \ \tau_2 = 2\,\mathrm{s}$$

The discrete-time linear model of the system for a sampling time $Te = 100$ ms using the CARMA model was applied to the heating central as

$$T(t) = 1{,}425.T(t-1) - 0{,}4966.T(t-2) + u(t) + 0{,}7919.u(t-1)$$

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