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Overview of Model Free Adaptive (MFA) Control Technology

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ABSTRACT

Model-Free Adaptive (MFA) control is a technology that has made a major impact on the automatic control industry. MFA control users have successfully solved many industry-wide control problems in various applications and achieved significant economic benefits. Now, the challenge is extending the many advantages of MFA control technology to diverse and fragmented markets, which could benefit from its unique capabilities. Since single-loop MFA controllers can directly replace legacy PID controllers without the need for "system" redesign (plugand play), they are readily embeddable in various instruments, equipment, and smart control valves. This alleviates concerns relative to cost of change and also makes MFA an appealing tool for OEM applications on a large scale.

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1. INTRODUCTION

Model-Free Adaptive (MFA) control, as its name suggests, is an adaptive control method that does not require process models. A Model-Free Adaptive control system is defined to have the following properties:

Precise quantitative knowledge of the process is not necessary;
Process identification mechanism or identifier is not included in the system;
Controller design for a specific process is not needed;
Manual tuning of controller parameters is not required; and
Closed-loop system stability analysis and criteria are available to guarantee the system stability

Variations of the core MFA control technology address specific control problems as described here.

1. SISO (Single Input Single Output) MFA to replace PID (Propotional, Integral, Derivative) controller so that manual controller tuning is eliminated,
2. Nonlinear MFA to control nonlinear processes,
3. MFA pH controller to control pH processes,
4. Feed forward MFA controller to deal with measurable disturbances,
5. Anti-delay MFA to control processes with large time delays,
6. Robust MFA to protect the process variable from running outside a bound,
7. Time-varying MFA controller to control time varying processes,
8. Anti-delay MFA pH controller for pH processes with varying time delays, and
9. MIMO (Multi Input Multi Output) MFA to control multivariable processes.

General-purpose or application-specific MFA controllers can be readily embedded and are becoming available on more and more platforms offered by various vendors supplying building controllers, single-loop controllers, programmable logic controllers (PLCs), hybrid controllers, process automation controllers (PAC), control software, and distributed control systems (DCS). [1]

2. CONCEPT AND SIGNIFICANCE OF MODEL-FREE ADAPTIVE CONTROL

A Model-Free Adaptive control system has the following properties and features:

1. No precise quantitative knowledge of the process is available;
2. No process identification mechanism or identifier is included in the system;
3. No controller design for a specific process is needed;
4. No complicated manual tuning of controller parameters is required; and
5. Stability analysis criteria are available to guarantee the closed-loop system stability.

The essence of MFA control is described with discussions relating to combustion process control on the following five issues:

2.1. Process Knowledge Issue

Most advanced control methods are based on a good understanding of the process and its environment. Laplace transfer functions or differential equations are used to represent the process dynamics. In many process control applications, however, the dynamics may be too complex or the physical process is not well understood. Quantitative knowledge of the process is then not available. This is called a “black box” problem.

In many cases, one may have some knowledge of the process but are not sure if the knowledge is accurate or not. In process control including combustion control applications, it is often deal with raw materials, wild inflows, changing fuel type and heating values, unpredictable downstream demand changes, and frequent switches of product size, recipe, batch, and loads. These all lead to a common problem: that is, one is not sure if the process knowledge is accurate or not. This is called a “gray box” problem.

If quantitative knowledge of the process is available, we have a “white box” to deal with. It is a relatively simple task to design a controller for the process in this case because we can use well-established control methods and tools.

Although Model-Free Adaptive control can actually deal with black, gray, and white box problems, it is more suitable to deal with the gray box problem. Most industrial processes are gray boxes

2.2. Process Identification Issue.

For traditional adaptive control methods, if the quantitative knowledge of the process is not available, an on-line or off-line identifier is required to obtain the process dynamics. This contributes to a number of fundamental problems:

1. The headache of off-line training that might be required,
2. The tradeoff between the persistent excitation of signals for correct identification and the steady system response for control performance,
3. The model convergence and local minimum problems, and
4. The system stability issues.

The main reason that identification-based control methods are not well suited forprocess control is that control and identification are always in conflict. Good control will lead to a steady state where setpoint (SP), controller output (OP), and process variable (PV) will show straight lines on a trend chart. Since any stable system can reach a steady state where process dynamic changes cannot be seen, good identification may require insertion of test signals. This requirement is not easily accepted by plant operators.

MFA control avoids the fundamental problems by not using any identification mechanism in the system. Once an MFA controller is launched, it will take over control immediately. The MFA algorithms used to update the weighting factors are based on a sole objective, which is to minimize the error between SP and PV. That means, when the process is in a steady state where error is close to zero, there is no need to update the MFA weighting factors.

3. CONTROLLER DESIGN ISSUE

The main reason PID is still popular is that it is a general-purpose controller that does not require controller design procedures. Designing a controller for a specific application requires special expertise. Since most advanced controllers are model-based, they cannot be a general-purpose controller. Thus, they are not widely used in process control, although these methods have been developed for 30 to 40 years.

MFA controllers are general-purpose controllers too. A number of MFA controllers have been developed to control a variety of problematic industrial loops. Examples include SISO MFA to replace PID and requires no manual tuning, Nonlinear MFA to control extremely nonlinear processes, Anti-delay MFA to control processes with large time delays; MIMO MFA to control multivariable processes; Feedforward MFA to deal with large measurable disturbances; and Robust MFA to force the process variable to stay within defined bounds.

For an MFA controller user, there are no controller design procedures required. One can simply select the appropriate controller as its name suggests, configure the controller with certain parameters and launch the MFA controller. This is one of the major differences between a Model-Free Adaptive controller and other model-based advanced controllers.

4. CONTROLLER PARAMETER TUNING ISSUE

An adaptive controller should not need to be manually tuned. This is also true for MFA controllers. MFA can adapt to new operating conditions due to changes in process dynamics, loads, or disturbances, and there is no manual tuning required. As a user-friendly feature, certain parameters are available to allow the user to quickly adjust the control performance.

5. SYSTEM STABILITY ISSUE

Control system stability analysis is always an important issue because it determines if the controller will be useful in practice. When the system stability criterion is available, one can use the criterion to decide if the control system can be safely put in operation.

The stability of the overall closed-loop control system is related to the process, the controller, and the model in the following way:

1. Stability of the process is assumed (i.e., the process is open-loop stable);
2. Stability of the control loop must be guaranteed by the convergence of the model; but
3. Convergence of the model is dependent on the stability and persistent excitation of signals originating from the control loop.

This is a circular argument that it is difficult to resolve. Thus, there is no general stability criterion available for a model-based adaptive control system. In other words, each time a model-based adaptive controller is used in a control system, its stability has to be analyzed. This is certainly a major technical barrier in applying model-based adaptive control methods.

In contrast, since MFA does not have an identifier, a general system stability criterion is developed. That is, if the process is passive (a process that does not generate energy or heat by itself), the closed-loop MFA control system stability is guaranteed, and the process can be linear/nonlinear, time invariant/time-varying, etc. A combustion process(for example, the internal combustion engine) is a passive process since the heat it generates has to come from burning fuel from outside of the process. [2]

6. SISO MODEL-FREE ADAPTIVE CONTROLLER

A single-loop MFA control system includes a single-input-single-output (SISO) process, a SISO MFA controller, and a feedback loop as illustrated in Figure 1.

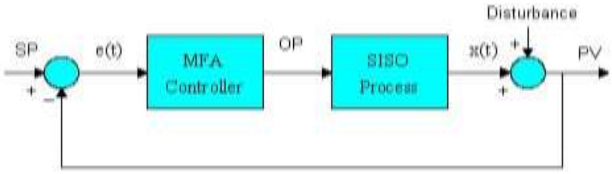

Figure 1. Single-loop MFA control system

The control objective is for the controller to produce an output u(t) shown in above Figure as OP to force the process variable y(t) shown in above figure as PV to track the given trajectory of its setpoint r(t) shown in above figure as SP under variations of setpoint, disturbances, and process dynamics. In other words, the task of the MFA controller is to minimize the error e(t) in an online fashion, where e(t) is the difference between the setpoint r(t) and the process variable y(t). The minimization of error e(t) is achieved by (i) the regulatory control capability of the MFA controller, and (ii) the adjustment of the MFA controller weighting factors that allow the controller to deal with process dynamic changes, disturbances, and other uncertainties. [4]

7. MFA CONTROLLER ARCHITECTURE

Figure 2 illustrates the core architecture of a SISO MFA controller. Used as a key component, a multilayer perceptron neural network consists of one input layer, one hidden layer with N neurons, and one output layer with one neuron.

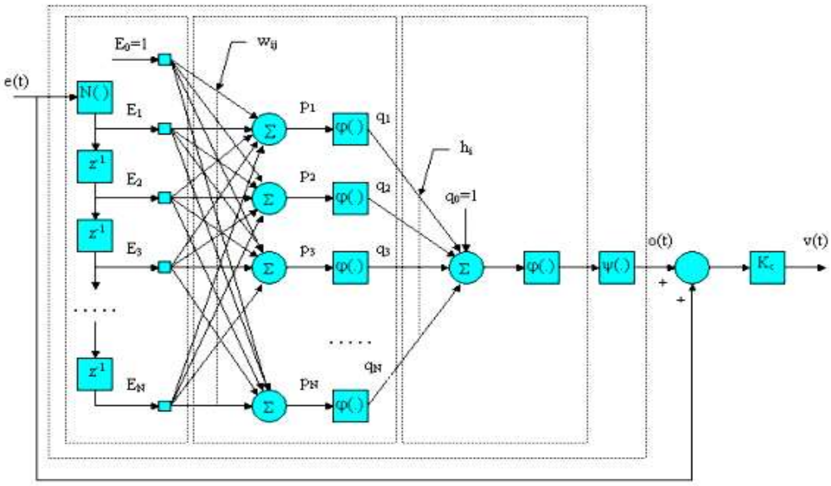

Figure 2. Architecture of a SISO MFA controller.

Within the neural network there is a group of weighting factors (wij and hi) that can be updated as needed to vary the behavior of the controller. The algorithm for updating the weighting factors is based on the goal of minimizing the error between the setpoint and process variable. Since this effort is the same as the control objective, the adaptation of the weighting factors can assist the controller in minimizing the error while process dynamics are changing. In addition, the artificial neural network based MFA controller "remembers" a portion of the process data providing valuable information for the process dynamics. In comparison, a digital version of the PID controller remembers only the current and previous two samples. In this regard, PID has almost no memory and MFA possesses the memory that is essential to a "smart" controller. [3]

A conceptual formula of an SISO MFA controller is given in the Equation 1:

$$U(t)=f(e(t), K, t) \qquad (1)$$

Where K is the MFA controller Gain .The weighting factors of the MFA controller are updated at every calculation cycle using a learning algorithm so as to produce the correct output U(t) to minimize the error e(t).

The actual algorithm governing the input-output of the SISO MFA controller consists of the following difference Equations:

$$p_j\,(n) = \sum_{i=1}^{N} w_{ij}\,(n)E_i\,(n) + 1 \qquad (2)$$

$$q_j(n) = \varphi\left(p_j\,(n)\right), \qquad (3)$$

$$o(n) = \psi[\varphi \textstyle\sum_{j=1}^{N} h_j\,(n)q_j(n) + 1], \; o(n) = \sum_{j=1}^{N} h_j\,(n)q_j(n) + 1 \qquad (4)$$

$$v(t) = K_c[o(t) + e(t)], \qquad (5)$$

Where n denotes the n th iteration, o(t) is the continues function of o(n), v(t) is the output of the Model-Free Adaptive controller, Kc> 0, controller gain, is a parameter used to adjust the magnitude of the controller output. This parameter is useful to fine tune the controller performance or keep the system within a stable range. Please refer to Figure 2 for the architecture of SISO MFA and its related parameters and variable.

An online learning algorithm is used to continuously update the values of the weighting factors of the MFA controller as follows:

$$\Delta w_{ij}(n) = \eta K_c e(n) q_j(n) \left(1 - q_j(n)\right) E_i(n) \sum_{k=1}^{N} h_k(n), \quad (6)$$

$$\Delta h_j(n) = \eta K_c e(n) q_j(n), \quad (7)$$

They are towards the goal of minimizing e(t), which is the difference between the set point and process variable.

8. MFA VERSUS OTHER CONTROL METHODS COMPARISON

Shown in Table 1 provides a comparison of PID, Model Predictive Control (MPC), Robust control design method, Model-based Adaptive control, and Model-Free Adaptive (MFA) control. It can be concluded that MFA combines the merits of all of these control methods and is the best candidate to be the next generation of mainstream process controller.

Table 1. Comparison of Control Methods

Compared Item	PID	Model Predictive	Robust Control	Model-based Adaptive	Model-Free Adaptive
General Purpose	Y	N	N	N	Y
Adaptive Capability	N	N	N	Y	Y
No process model	Y	N	N	N	Y
No identification	Y	Y	Y	N	Y
No controller design	Y	N	N	N	Y
No controller manual tuning	N	Y	Y	Y	Y
Stability criteria available	Y	Y/N	Y	Y/N	Y
Easy to use and maintain	N	N	N	N	Y
Candidate for next generation mainstream controller	N	N	N	N	Y

9. CONCLUSION.

MFA is neither model-based nor rule-based. It can be said that it is an information-based control method. If the argument is made that the process information used is equivalent to a process model, that's perfectly acceptable. The key to this approach is that we focus on delivering a simple, adaptive, and effective solution. Users can simply select the appropriate MFA, configure its parameters, launch the controller, and reap the benefits. With the proper approach, no manual tuning and maintenance is required.

REFERENCES

[1] Ali, Haider, et al. "Implementation & Comparative Analysis of 10, 18 & 24 Level Diode Clamped Inverters Using“ Trust Region Dog Leg ”Method." *Circuits and Systems* 6.03 (2015): 70.

[2] George Shu-Xing Cheng, MFA in Control with CyboCon, Fifth Edition, Cybosoft, *General Cybernation Group*, 2007.

[3] George Shu-Xing Cheng, “Model Free Adaptive (MFA) Control,” *IEE Computing and Control Engineering*, June, July 2004.

[4] George Cheng and Qiang Wang, Model Free Adaptive Control of Evaporators, *IEEE Digital Library*, August, September 2005.

[5] Vance J. VanDoren, An Overview of Commercial Techniques for Adaptive Control, *IEE Computing and Control Engineering*, June, July 2004.

[6] Cheng, George Shu-Xing, Steven L. Mulkey. "Model-free adaptive (MFA) optimization". U.S. Patent No. 7,415,446. 19 Aug. 2008.

[7] Xu, Aidong, Yangbo Zheng, Haibin Yu. "*Research on the application of model free adaptive (MFA) control in gas turbine.*" Electronic Measurement & Instruments, 2009. ICEMI'09. 9th International Conference on. IEEE, 2009.

[8] Bu, Xu-Hui, Zhong-Sheng Hou, and Shang-Tai Jin. "The robustness of model-free adaptive control with disturbance suppression." *Control Theory & Applications* 28.3 (2011): 358-362.

[9] Wang, Jing, et al. "Model free adaptive control and parameter tuning based on second order universal model." *Journal of Central South University (Science and Technology)* 43.5 (2012): 1795-1802.

[10] Al Smadi, Takialddin, Farouq M. Al Taweel, and Al-Khawaldeh Igried. "Estimation and Design Techniques for Adaptive Delta Modulation Using Otas."

[11] Al Smadi, Takialddin A. "Design and implementation of double base integer encoder of term metrical to direct binary." *Journal of Signal and Information Processing* 4.04 (2013): 370.