International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 2, February - 2014

Grey Prediction Algorithm Based Fuzzy Logic Controller for Temperature Process

Saravanan. P
PG Student
Department of Electronics and
Instrumentation Engineering
Karunya University,Coimbatore

L. D Vijay Anand
Assistant Professor
Department of Electronics and
Instrumentation engineering
Karunya University, Coimbatore

Abstract **-Measuring and controlling the temperature is a critical need in many industrial processes. The control of temperature using conventional Fuzzy with PI(proportional Integral) controller results in increased settling time, steady state error, and increase in rise time owing to nonlinear nature of process. Fuzzy with PI controllers are widely used in the process control applications, but they exhibit poor performance when used applied to the system, as controlling will be difficult due to in sufficient knowledge of parameters in the system. But these controllers ie conventional controllers have no prediction capabilities. Grey Prediction model GM(1,1) combined with Fuzzy with PI controller is designed to control the final control element of the temperature process station. The purpose of the GM(1,1) model is to work on system forecasting with poor , uncertain or incomplete messages. The Grey Fuzzy with PI controller can predict the future output value of the system. The Fuzzy with PI/Grey predictor controller is illustrated by means of computer simulation test in MATLAB environment. The simulation results points that, suggested Grey Fuzzy with PI has capability in controlling the considered system with fast rise time and minimized settling time.**

Keywords-Fuzzy logic controller, conventional PI, Grey Prediction, Temperature process.

I. INTRODUCTION

In control theory, the amount of clear information is represented in terms of color to define a system. A system is known as "black box" if its internal characteristics or mathematical equations that describes the system is completely unknown. Similarly if the system description is completely known, then we say that system as "white box". On the other hand if the system has both unknown and known information then such systems are defined as "grey box". In real life almost all systems can be considered as grey systems since all parameters are not completely known.

The Grey theory has become popular with its ability to deal with the systems which have partially unknown parameters. The grey theory works mainly on systems with incomplete, poor or uncertain messages. A grey prediction model is one of the most important part in grey system theory, and that , the GM(1,1) model is core of Grey Prediction.

The grey prediction algorithm has the ability to predict the output or error in the system depending on small amount of data. The grey theory deals with partially known and partially unknown information's. The output of grey controller is updated using the prediction error for the better controller performance.

The natural world is numerous and totally disordered. These words give a feeling of grey, hazy, and fuzzy. Even though technology has developed we still face problems in systems regarding the constraints, parameters and their availability. Many of such problems are out of control. The meaning of prediction is that we can predict all unknown data's , parameter's through known known and unknown models. The characteristics of predictable models are connecting the reality and future, The joining of one matter which has happened and the other matter which is going to happen and communicate the unknown and known data with a mathematical model.

In order to make the model predictable, following characteristics should be met. The model must be evident and implicit in relation. The model should be an extrapolation. The predicted data can cope with future situation. Before prediction the model should be examined by some methods and concepts to see if it is reasonable or not.

The classification of the prediction model is divided into two parts, one is "behavior model" and the other is "factor model". The former is used as behavior data to build the prediction model and the later is used as influence factor data to build the prediction model.

II. CATEGORIES OF METHODS

There are more than 500 kinds of prediction method in modern time. This includes Delphi method, Regression method, Trend method, Markov method, Modelling method , etc.

A. Linear Regression

A problem is to determine the relationship between a random variable Y and independent classic statistical variable X.

B. Multiple Regression

The general purpose is to learn more about the relationship between several independent or predictor variables and a dependent or criterion variable.

C. Delphi Method

Technology forecast studies, eventually led to the development of the Delphi method started in1944. The main objective is the reliable and creative explorations of ideas or the production of suitable information for decision making.

D. Trend Prediction Method

The meaning of trend prediction is based on different target and object to do the trend prediction and to try to find the future trend of the target and item.

E. Modelling Method

The definition of this method is a large data to build up a transfer function of time, such like Grey system model.

F. Markov Method

The definition of this method is a random process whose future probabilities are determined by its most recent values.

III. CATEGORIES OF PREDICTION

The main purpose of the grey system theory focuses on the relation between the analysis model construction, and circumstances such as no certainity, multi data input, discrete input and insufficient data through predicting and decision making. The grey prediction only use little date to predict the next , and can be divided into five parts.

A. Sequence Prediction

This is to predict the characteristic trend of a system, and based on the data in that system, like prediction of sale in company, the prediction of population in a country, the total bank savings, the amount of cargo etc.

B. Season Prediction

This is to find the weather characteristics, like the spring rain appearing in what data, and predict when the frost will appear in September, October or November.

C. Composite Prediction

This is to find out the whole dynamic relationship in the system and to build up the dynamic flame of the system.

D. Topology Prediction

This predicts the behavior during a fixed interval.

E. Disaster Prediction

This is to predict the threshold value of a system and use this threshold value as the reference point to make a decision, like the threshold of human blood pressure. If the value is lower than the threshold, then call it as normal, otherwise, it is called as high blood pressure.

IV. TEMPERATURE PROCESS

Here we are dealing with nonlinear systems that is output is not linear to input. Thus temperature is one such process. Controlling temperature to a desired value is not so easy without proper details of the plant. Thus it's a challenge in creating a controller with predictor. Here we use grey predictor algorithm to predict the future value before effecting the system by using a FLC. To create environment with varying temperature furnace is used and sensor is placed at one end. Thus blower is used to get that heat near sensor with uniform distribution.

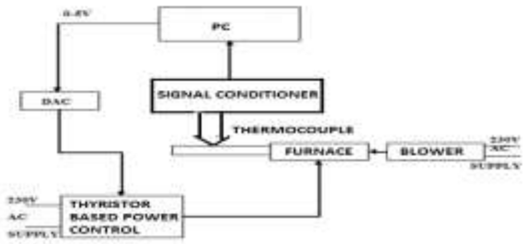

Fig. 1. Block diagram for temperature process

The PC is installed with MATLAB and grey prediction with FLC is designed. Thus PC controls the whole system as required.

V. GREY PREDICTION CONTROLLER

A time series is a collection of data points which are generally sampled equally in time intervals. Time series prediction actually refers to a process by which the future values of a system is forecasted based on the information obtained from past and current data points. A predefined mathematical model is used to make an accurate predictions. Time series prediction models are widely used in financial area and so on.

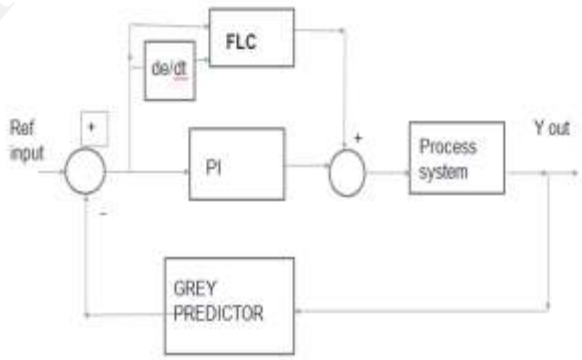

Fig. 2. Block diagram of PI with Fuzzy and Grey Controller

Grey theory was introduced in 1982. The grey theory deals with indeterminate and incomplete data to analyze and establish the systematic relations and prediction model. Unlike other conventional controllers grey controller simply requires four or more lagged inputs to construct a grey differential equation. The grey prediction has widely used in studies of social science, agriculture, power consumption, procreation and management, as well as other fields. In grey theory, two techniques are used to establish the model for applications. They are accumulated generating operation (AGO) and inverse accumulated generating operation (IAGO).The grey prediction model does IAGO on the original sequence and the resultant new series is used to generate a difference equation whose coefficients are found via least square method. The accumulated generating series prediction model value is then obtained. The estimated prediction value in the time domain is calculated by means of an inverse accumulated generating operation. A few original sequence elements are needed and one does not have to assume the distribution of the sequence. The generated value is then used to establish a set of grey difference equation and grey pseudo differential equation. This is called the grey model.

A. Generation of Grey Sequence

The main task of grey system theory is extracting governing laws of the system using available data. This process is known as the generation of grey sequence (Liu & Lin, 1998). It is said that even though the available data of the system, which are generally white numbers, is too complex, they always contain some governing laws. If the randomness of the data obtained from a grey system is somehow smoothed, it is easier to derive any special characteristics of that system (Chia Chang Tong 2006).

For instance, the following sequence that represents the price of a product might be given:

X(0)=p (820, 840,835,850,890)

It is clear that the sequence does not have a clear regularity. If accumulating generation suggested in grey system theory is applied to this sequence, X(0) is obtained which has a clear growing tendency.

X(0)= P(820,1660,2495,3345,4235)

B. GM(N,M) Model

In grey systems theory, GM(n,m) denotes a grey model. And 'n' is the order of the difference equation and m is the number of variables. Although various types of grey models can be mentioned, most of the previous researchers have focused their attention on GM(1,1) models in their predictions because of its computational efficiency. It is clear that in real time applications of temperature process, the computational burden is the most important parameter after the performance.

C. GM(1,1) Model

GM(1,1) type of grey model is the most commonly used in the literature, pronounced as ''Grey Model First Order One Variable". This model is a time series forecasting model. The differential equations of the GM(1,1) model have time-varying coefficients. In other words, the model is recreated as the new data become available to the prediction model.

In order to smooth the randomness, the primitive data obtained from the system to form the GM(1,1) is subjected to an operator, named Accumulating Generation Operator (AGO). The differential equation (i.e. GM(1,1)) is solved to obtain the n-step ahead predicted value of the system. Finally, using the predicted value obtained, the Inverse Accumulating Generation Operator (IAGO) is then applied to find the predicted values of original data.

GM (1, 1): This represents first-order derivative, containing one input variable, commonly used for prediction purposes.
GM (1, N): This represents first-order derivative, but contains N input variables, for multi-variable analysis.
GM (O, N): This represents zero-order derivative, containing N input variables, for prediction purposes.

The GM (1, 1) model is established to perform the prediction of system output response. The standard procedure is as follows:

Step 1: Collecting the original data sequence

$$X^{(0)} = \left\{ x^{(0)}(1), x^{(0)}(2), \ldots x^{(n)} \right\} \qquad n \geq 4 \qquad (1)$$

Step 2: Conducting an accumulated generation operation, AGO, on the original data sequence in order to diminish the effect of data uncertainty;

$$X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots . x^{(0)}(\mathrm{n})) = (x^{(0)}(\mathrm{k}))$$

where k=1,2,3,…n.

$$AGO\left\{ (x^{(0)}(\mathrm{k})) \right\} = x^{(1)}(k)$$

$$= \sum_{k=1}^{1} x^{(0)}(k), \sum_{k=1}^{2} x^{(0)}(k), \ldots . \sum_{k=1}^{n} x^{(0)}(k) \qquad (2)$$

Step 3: Establishing grey differential equation and then calculating its background values; first we define Z(1) as the sequence obtained by the MEAN operation to x(0) as follows;

$$z^{(1)}(\mathrm{k}) = MEAN\, x^{(1)} = 0.5(x^{(1)}(K) + x^{(1)}(k-1)$$

Where,k=1,2,3,…..n (3)

Secondly grey differential equation can be obtained as follows;

$$x^{(0)}(K) + az^{(1)}(\mathrm{k}) = \mathrm{b} \qquad (4)$$

Step 4: First thing for GM (1, 1) model, is to calculate the values of parameters *a* and *b*. and is called the least square method. Where the parameters *a*, *b* are called the development coefficient and the grey input, respectively, from equation,

$$x^{(0)}(k) + az^{(1)}(K) = b \quad \text{Substitute all value} \qquad (5)$$

$$x^{(0)}(1) = -az^{(1)}(2) + b$$

$$x^{(0)}(2) = -az^{(1)}(3) + b$$

$$x^{(0)}(3) = -az^{(1)}(4) + b$$

....

$$x^{(0)}(n) = -az^{(1)}(n) + b$$

Transfer equation (5) into matrix $Y = b^{\wedge}a$ then we have

$$Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ x^{(0)}(4) \\ \dots \\ x^{(0)}(n) \end{bmatrix}, \quad B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ -z^{(1)}(4) & 1 \\ \dots\dots & \dots \\ -z^{(1)}(n) & 1 \end{bmatrix}, \quad a^{\wedge} = \begin{bmatrix} a \\ b \end{bmatrix} \qquad (6)$$

$$Y = b^{\wedge}a$$

$$\begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ x^{(0)}(4) \\ \dots \\ x^{(0)}(n) \end{bmatrix} = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ -z^{(1)}(4) & 1 \\ \dots\dots & \dots. \\ -z^{(1)}(n) & 1 \end{bmatrix} \times \begin{bmatrix} a \\ b \end{bmatrix} \qquad (7)$$

In above is a sequence a, b of parameters that can be found as follows:

$$a^{\wedge} = \left(B^{-1}B\right)^{-1} B^{T}Y \qquad (8)$$

Step5: AGO prediction,

$$x^{(0)}(k+1) = (x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)} + \frac{b}{a} \qquad (9)$$

Step 6: Applying IAGO (Inverse Accumulation Generation Operation), to original sequence

$$x^{(0)}(k+1) = (x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)}(1 - e^{(a)}) \qquad (10)$$

VI. FUZZY LOGIC CONTROL

Obviously comparing with conventional controllers, FLC has the ability to control nonlinear, time invariant, time delayed and complex processes. But the procedures of fuzzy control algorithm involve the powerful software and big volume of memory to implement which is not seen in conventional controllers. The heart of fuzzy controller is rule base that shows the control laws in a human expert natural language basis. The number of rules is determined based on the number of fuzzy subsets for each fuzzy input/output variable. The rule base is shown in table 1. Fuzzy logic actually deals with many valued logic. It deals with reasoning. Fuzzy logic variables have truth value ranging between 0 and 1. The truth value completely ranges between true and false. For developing sophisticated control systems, fuzzy logic has widely become the most attractive algorithm. Here PI controller is also used in addition to FLC which forms a intelligent system. And grey predictor is used in feedback which acts like a sensor. Thus any changes seen is forecasted by grey predictor before it effects the system.

Table 1: Rule base

e / $\dot{e}$	NL	NM	NS	ZR	PS	PM	PL
PL	ZR	PS	PM	PL	PL	PL	PL
PM	NS	ZR	PS	PM	PL	PL	PL
PS	NM	NS	ZR	PS	PM	PL	PL
ZR	NL	NM	NS	ZR	PS	PM	PL
NS	NL	NL	NM	NS	ZR	PS	PM
NM	NL	NL	NL	NM	NS	ZR	PS
NL	NL	NL	NL	NL	NM	NS	ZR

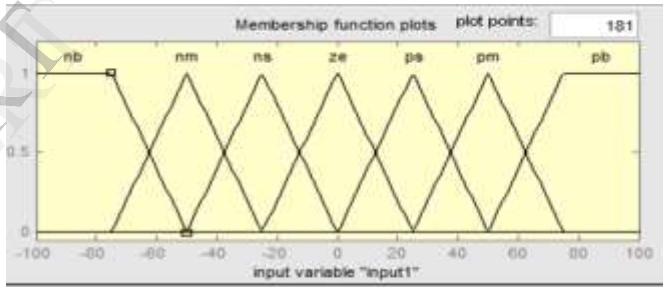

Fig. 3. Membership functions of error, derivative of error and output

In this paper, temperature is transformed in terms of negative big (NB). Negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), positive big (PB). Such transformation is called as membership function. Membership function defines both the range of the value and degree of membership. Membership function in this paper is created for error, derivative of error, and output as shown in fig 3.

VII. PI CONTROLLER

The controller used is PI controller since temperature process is a slow process. The fixed gain controller is suitable if the operating condition does not change, but when the operating condition changes continuously the fixed gain controller is not suitable. For each operating region the PI controller settings will differ. One methods used to fix the problem is gain scheduling. Here we deal with PI controller only. The PI control scheme is named after its two correcting terms, whose sum constitutes the manipulated variable (MV). The proportional and integral terms are summed to calculate the output of the PI controller. Defining U(t) as the controller output, the final form of the PID algorithm is;

$$u(t) = k_p e(t) + k_i \int e(t)dt$$

where ;

k_p : Proportional gain, a tuning parameter

k_i : Integral gain, a tuning parameter

e: Error = SP – MV

t : Time or instantaneous time (the present)

For temperature process control PI control can be used with low controller gain. Use of PI control gives more accuracy with high integration activity. Derivative control is not considered due to the rapid fluctuations in flow dynamics with lots of noise.

VIII. CONTROL ACTION OF PI AND FUZZY

In order to design a PI with fuzzy controller , design a fuzzy controller with two inputs: error, and rate of change of error. Unlike the conventional controllers, the procedures of fuzzy control algorithm involve the powerful software and big volume of memory to implement.In order to make fuzzy rules, one should be aware about the process and its response to various set points. Thus rules are important in getting desired output. The more rules we use the more precise would be the output.

IX. CONTROL ACTION OF PI, FUZZY AND GREY CONTROLLER

Based on the control system structure, we can get control system simulation model for a step change using MATLAB environment. It was seen that PI with fuzzy and Grey controller takes a control action and gives a controller output.Here grey algorithm is used to predict future value which reduces error. When a sensor is used in feedback it senses or gets an input with some time interval. But within that interval due to any reason input may vary and thus it want be sensed. But if we design a controller which could predict the value and thus control action would be taken before it effects the system. Thus the response obtained shows that control action is taken with reduced overshoot and fast settling time as expected.

X. RESULTS OBTAINED

In comparing with the conventional controllers, fuzzy controllers have a high ability to control nonlinear, time invariant, time delayed and complex processes. Figure 4 shows the response of PI , Fuzzy controller. Thus response of controller has increase in rise time and settling time for temperature process system.

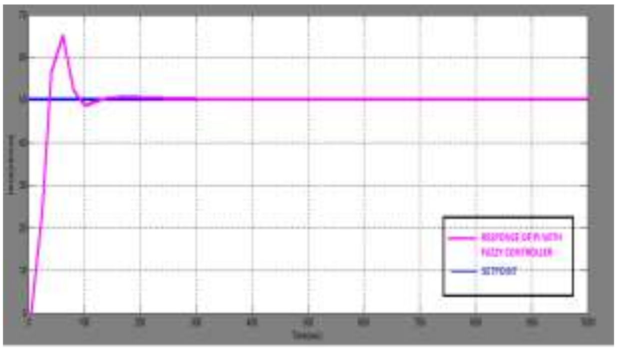

Fig. 4: Response of PI , fuzzy controller implemented in MATLAB

Fig 5 shows the response of PI, fuzzy and Grey controller implemented. PI type Fuzzy controller is implemented in order to eliminate the steady-state error and oscillation. Control methods, essentially based on conventional PID theory, have no predictive capabilities.

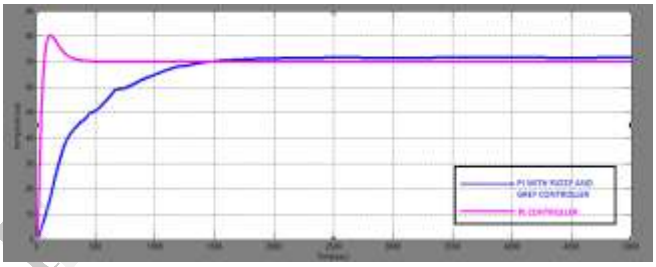

Fig. 5: Response of PI, Fuzzy and Grey controller implemented in MATLAB

As can be seen, grey controller has better rise time but settling time with little tolerance.

XI. CONCLUSION AND FUTURE WORK

In real life, the mathematical model of a physical system cannot be defined exactly; there are always some uncertainties. Grey prediction control has advantages of less data, poor information and small computation, and the fuzzy logic reasoning has the characteristics of nonlinear function approximation. Combining grey prediction with fuzzy with PI control strategy is put forward, and it is applied to temperature process. A model which can integrate the advantages of fuzzy controller and grey predictor to reduce the settling time, and adjust the rising time by taking the proper sampling n. The prediction capability of the algorithm is analysed and simulation results have been presented to show its effectiveness. In contrast with the Fuzzy PI controller, the GM (1,1) algorithm gives more accurate results. Moreover, as the dynamics of the input signal changes, the proposed algorithm still gives a better prediction results.

The project can be enhanced with the GA or Neural Network based Grey control in LabVIEW and the results can be compared with above implemented controllers.

REFERENCES

1. Er. Rakesh Kumar, Er. H.S Dhaliwal, Er. Ram Singh,"Intelligent Fuzzy-PID Hybrid Control for Temperature of NH3 in Atomization Furnace",International journal of engineering sciences ISSN:2229-6913 Issue sept 2011, Vol. 4 June,2012.
2. Erdal Kayacan. Baris Ulutas and Okyay Kayanak,"Grey System Theory-Based Models In Times Series Prediction", Elsevier Journal,2010.
3. Ala Eldinosbi Bin Mamat ,"Self PID Tuning Rulre Using Grey Prediction Algorithm",Department of Mechatronics and Robotics, University Teknologi Malaysia,2009.
4. Kun-Li Wen(, "A Matlab Toolbox for Grey Clustering and Fuzzy Comprehensive Evalution", Elsevier Journal, Department of Electrical Engineering, Grey system research center(GSRC) Taiwan,2007.
5. Bogdan Zoltowski, "Consideration in Diagnostics of the Grey System Theory", Journal of polish cimac,2007.
6. Chia-Chang Tong and Enrique, "Design of Refined Grey Prediction Controller", IEEE International conference on systems, Taiawan,2006.
7. Kun-Li Wen and Ting- Cheng Chang, " The research and development of completed GM(1,1) Model Toolbox Using Matlab", International Journal of Computational Cognition,VOL. 3, No.3,Sept,2005.
8. Erdal Kayacan Ala, Okyay Kayanak,"Grey Prediction Based Control of a Non Linear Level System using PID Type Fuzzy Controller",IEEE 3rd International Conference on mechatronics,2006.