Adaptive Control Framework Study Based on Fuzzy Cognitive Map

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Abstract: - In this paper, we present an adaptive control framework, which study combines control theory with fuzzy cognitive map theory. The proposed framework utilizes the feature and the inference mechanism of FCM. The causal relationship of variables is constructed by online learning, the values of control variables are given by the inference of FCM model, and the control variables are used to adjust the controlled variables in actual process and carries out the control of multi-input and multi-out. Finally, an illustrative example is provided, its results suggest that the method is capable of FCM model.

Key-Words: - fuzzy cognitive map, adaptive control, system modeling, control framework

1 Introduction
Control technology has played a key role in the development of science and technology. The traditional control, which includes the classical feedback control, modern control, modern control theory and large-scale control system, has encountered many difficulties in its applications. First of all, the design and analysis for the traditional control systems are based on their precise mathematical models that are usually difficult to achieve owing to the complexity [1], nonlinearity, uncertainty, time-varying, and incomplete characteristic of the existing practical systems. On the other hand, some critical hypotheses have to forward in studying and modeling the control systems, these hypotheses are hard to match in practice. For these reasons, automatic control has been looking for new ways to overcome the difficulties; one of the more effective ways to solve the problems mentioned above is to use the technique of intelligent control to the control systems, or to apply a hybrid methodology of the traditional and intelligent control techniques to the control systems[2,3,4,5]. The core of the new ways is the intellectualization of controller. In this paper, we present an adaptive control framework. The study combines control theory with FCM theory, and the feature and the inference mechanism of FCM are used. The proposed method can provide a novel control method.

The paper is organized as follows. Section 2 presents the Formalization and the inference process of FCM. Section 3 introduces the control framework based on FCM. Section 4 is the conclusion and suggestions for future works.

2 Fuzzy Cognitive Map
Fuzzy cognitive map (FCM) is a soft computing method for simulation and analysis of complex system, which combines the fuzzy logic and theories of neural networks. Kosko introduced them as an extension of cognitive map in 1986. It has several desirable properties, such as, it is relatively simple to use for representing structured knowledge, and the inference can be computed by numeric matrix operation, most importantly, they are flexible in system design, model and control, the comprehensive operation and the abstractive representation of behavior for complex systems, it has strong online and offline learning ability.

2.1 Formalization of Fuzzy Cognitive Map
A FCM consists of nodes-concepts, each node-concept represents one of the key-factors of the system, and it is characterized by a value $C \in (0,1)$, and a causal relationship between two concepts is represented as an edge $w_{ij}$. $w_{ij}$ indicates whether the relation between the two concepts is direct or inverse. The direction of causality indicates whether the concept $C_i$ causes the concept $C_j$. There are three types of weights:
A fixed point: if the FCM equilibrium state of a dynamical system is a unique state vector, the state vector remains unchanged for successive iterations, then it is called the fixed point.

\[ X(k+1)=X(k) \tag{3} \]

A limit cycle: if the FCM settles down with a state vector repeating in the form

\[ A_1 \rightarrow A_2 \rightarrow \ldots \rightarrow A_i \rightarrow \ldots \rightarrow A_1 \]

Or

\[ X_{j=r} = f(WX_j), \quad j=1,2,\ldots, r-1 \]

\[ X_r = f(WX_r) \]  \tag{4}

then this equilibrium is called a limit cycle.

We pass state vectors \( X \) repeatedly through the FCM connection matrix \( W \), thresholding or non-linearly transforming the result after each pass.

\[ X(t+1) = \begin{bmatrix} x_1(t+1) \\ x_2(t+1) \\ \vdots \\ x_n(t+1) \end{bmatrix} = f(WX(t)) = f(\begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ \vdots \\ x_n(t) \end{bmatrix}) \]

We illustrate this by the following example:
The first concept node vector be: \( X_1=(1 \ 0 \ 0 \ 0 \ 0) \), the connection matrix \( W \)

\( X_1W=[0,0,-1,0,1] \quad X_2=f(X1W) \quad (1,0,0,0,1)=X_2 \\
X_2W=[0,0,-1,1,1] \quad X_3=f(X2W) \quad (1,0,0,1,1)=X_3 \\
X_3W=[-1,1,-1,1,1] \quad X_4=f(X3W) \quad (1,1,0,1,1)=X_4 \\
X_4W=[-1,1,-1,1,1] \quad X_5=f(X4W) \quad (1,1,0,0,1)=X_5 \\
X_5W=[0,0,-1,0,1] \quad X_6=f(X5W) \quad (1,0,0,0,1)=X_6=X_2 \)

so \( X_2 \) is a fixed point of the FCM dynamic system.

This example illustrates that we can apply this kind of FCM-based forward-evolved inference approach to decision-making problems.

### 3 A adaptive control framework based on FCM

Adaptive control system can make conditional decision in the environment with uncertainties. The controller is required to have stronger adaptively, real-time capability and fine control quality.

The control based on FCM is a closed loop control method, it is shown in Fig.3. It can replace traditional controller to complete all function.
3.1 The control framework
The control framework utilizes the feature and the inference mechanism of FCM. The causal relationship of variables is constructed by online learning, the values of control variables are given by the inference of FCM model, and the control variables are used to adjust the controlled variables in actual process and carries out the control of multi-input and multi-out [6,7]. The control framework is shown in Fig. 4.

The proposed control framework has three layers, below we will discuss each layer of the frameworks what should is done in turn.

(1) The Physical layer. The layer is the physical system of devices that measure the control variables of the process and can carry out the control of process. It is concerned with accepting the control information transmitted by upper layer and transmitting the collected data of sensors to the upper layer.

(2) The data interface layer. This layer have three functions: (a) the information is organized and classed; (b) the information is transformed into FCM term and transmitting to model layer; (c) the information of the upper layer is accepted, organized and transformed into real system required format and transmitting to the physical layer.

(3) The model layer. The key function obtains the value of control variables by inference according to input state, and transforms, transmits them to the data interface layer.

3.2 The main process explanation
3.3.1 Selecting method of the state value
We use an example to explain the method of obtaining the value of control variable.
Example: node number n=4, start state vectors X(0) = (0.264, 0.679, 0.512, 0.322) at t time, the connection matrix is W:

\[
W = \begin{bmatrix}
0 & 0 & 0.765 & 0 \\
0.315 & 0.812 & 0.543 & 0 \\
0 & 0 & 0.875 & 0 \\
0.215 & 0 & 0 & 0
\end{bmatrix}
\]

At each simulation step of the FCM, the values of concepts are calculated according to below formula:

\[
y(t+1) = f(u_i) = f\left(\sum_{j \neq i}^n W_{ij} X_j(t)\right)
\]

The FCM interacts for the initial values of concepts. In table 1 the values of concepts for eleven simulation steps are represented, it can be seen that after only eight simulation steps, the FCM reaches a fixed equilibriums point: 0.615411, 0.727684, 0.614531, 0.53303. It must be mentioned that the duration of each simulation step is one time unit. The equilibriums point is a needed result.

Table 1. the values of FCM concepts for eleven simulation steps

<table>
<thead>
<tr>
<th>x1</th>
<th>x2</th>
<th>x3</th>
<th>x4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.264</td>
<td>0.679</td>
<td>0.512</td>
<td>0.322</td>
</tr>
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<td>0.596687</td>
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<td>0.532992</td>
</tr>
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<tr>
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<td>0.727684</td>
<td>0.614531</td>
<td>0.53303</td>
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</table>

3.3.2 The adaptive control principle of FCM
The work of the control system is divided two stages, control period and learning period. When kth control period start, let input state vector X(k), according to the formula (1) to get ym(k+1).

The values of control variables from the output model ym(k+1) are translated to the data interface layer, the concepts value are transformed physical...
signal and the information is organized, filtered, translated to control part of system. The control part of system will determine the control actions that must be applied to the process and some variables of the process will be influenced by the control signals.

The weights of the interconnections will be adjusted according to existing measurements and data on the operation of the system. The different value between the output of system with the output of FCM model is as training signal. The learning method is a supervised learning, system provides goal value as teacher. In the learning stage, the real output is $y_p$, the output of FCM model is $y_m$, the weight of FCM is adjusted according to the learning rule.

$$\Delta w = \alpha (y_p - y_m) / c$$  \hspace{1cm} (5)

where, $\Delta w$ denotes the change of weight, $\alpha$ is learning rate, $c$ is generalized coefficient, $y_p - y_m$ is the different of The different value between the outputs of system with the output of FCM model.

When system is running, the connection matrix is constructed, the weight of FCM is adjusted along with learning, and the output of the model approximates the real system.

3.3.3 The application process statement

The adaptive control process of FCM is a process that control while learning. In the adaptive framework, FCM is an adjustable controller, it can on-line learn weight parameter. Generally, recurrence method is used in the online learning. In the study, we use $\delta$ learning.

(1) First all, we analysis problem and make certain the control variable and controlled variable of system.

(2) The control variable and the controlled variable can be represented the model of system and its operational behavior. In the study, we use $\delta$ learning to construct FCM.

(3) The FCM is initialized; each concept takes an initial value.

(4) The control information is inputted, the controlled variables will be changed in the value of concept of the FCM, and concepts of the FCM interact each other until a fix point is reached.

(5) If the control goal is reached according to the fact of being observed, the control process finish, otherwise the control variables from the model of FCM is taken out, go to step 4. Repeat implement until arrives control goal of system.

4 Conclusion

We presented an adaptive control framework, which study combines control theory with fuzzy cognitive map theory. We analysis the control principle and the control steps of FCM. The proposed framework utilizes the feature and the inference mechanism of FCM. The causal relationship of variables is constructed by online learning, the values of control variables are given by the inference of FCM model, and the control variables are used to adjust the controlled variables in actual process and carries out the control of multi-input and multi-out.

References:


