Study on Flexible Universal Logics Intelligent Control

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Abstract—In the face of the complex controlled object, environment and control task, the intelligent control methods show the greater advantage and broader development prospects than the traditional ones. The logic foundation of current intelligent control methods are mainly classical logic and fuzzy logic. The classical logic is only suitable for describing the completely opposite binary world. Fuzzy logic admits the flexibility of true value. However its proposition conjunctions are rigid. So, the flexibilization problem for the intelligent control model is studied here. And a flexible intelligent control method based on universal logics is proposed. Because its logic foundation admits the flexibilities of true value, proposition conjunctions, quantifier and the reasoning, the control method can simulate the human’s control methods better. The successful control experiments for typical linear and nonlinear systems prove the validity of proposed method.

Keywords—intelligent control; flexibility; universal logics; correlation

I. INTRODUCTION

Along with the rapid development of modern science, the scales of the production systems become bigger, and the large complex system appears. The large complex system consists of many sub-systems which interact with and separate from each other. All kinds of changeable sub-tasks with different priorities should be satisfied with their performance targets at the same time or in proper sequence. This kind of nonlinear, chaotic and uncertain dynamic action make the controlled object, controller and control tasks become more and more complex.

So the traditional control theories and methods should be improved though they have made great economic benefits in the past. And many intelligent control methods with cognition and imitating-human functions appear[1]. These intelligent control methods display the validity and advantage when they deal with the uncertain reasoning problems which exit in random, fuzzy, approximate and incomplete knowledge.

The logic foundation of current intelligent control methods are mainly classical logic and fuzzy logic. The classical logic is only suitable for the completely opposite binary world and can not describe the real world. Fuzzy logic has the character of proposition flexibility. However its proposition conjunctions are rigid yet. In this paper, a flexible intelligent control method based on universal logics is proposed. Because the true value, proposition conjunctions, quantifier and reasoning are all flexible in universal logics, the proposed controller here can reflect the real world more actually. The experiments prove that the controller can control linear and nonlinear system rapidly and validly.

II. THE THEORY FOUNDATION OF FLEXIBLE UNIVERSAL LOGICS CONTROL

Intelligent control is an interdisciplinary subject in science. And artificial intelligence is its indispensable part. During the early stage of development of artificial intelligence, standard logic as the fundamental theory plays the main role. Along with the development of study, the people realize that not only logical reasoning and heuristic search functions but also expert knowledge and common sense make human being solve complex problem rapidly and validly. So, we can try to make some kind of logic which is reliable, about uncertain reasoning, opened and adaptive as the theory foundation of reasoning about expert knowledge and common sense. Then this kind of reasoning could be used to solve the control problem for complex system.

Universal logics proposed by Prof. He Huacan is a continuous and controllable logic system which has made a breakthrough in solving uncertain problem[2][3]. By referring to the concept of general correlation which reflects the relation between objects, universal logics unifies all kinds of uncertain proposition conjunction operation models. There are two kinds of correlation. The one is general self-correlation denoted by coefficient \( k (k \in [0,1]) \), namely the measurement error for true value of proposition, which changes continuously from the maximal possible negative error to the maximal possible positive error. The other is general correlation denoted by coefficient \( h (h \in [0,1]) \), namely the relationship between two propositions, which changes continuously from the maximal correlation to the minimal correlation. In universal logics, these two kinds of correlations extend the flexibility of true value further to flexibility of proposition conjunction. Then based on these two kinds of flexibilities and flexibility of quantifier, the flexibility of reasoning is obtained.

Universal combination operation model is a flexible proposition conjunction in universal logics. Because of its integrated decision-making function, universal combination model can be used as the reasoning model of intelligent control system. It satisfies the mapping \( C^e: [0,1] \times [0,1] \rightarrow [0,1] \), which has three parameter \( e \), \( h \) and \( k \). \( e \) is the identity element, \( h \) is the general correlation coefficient, and \( k \) is general self-correlation coefficient. In the controller, these three parameters could be used as decision-making threshold.
value, relation measurement between input variables and measurement error. The universal logics controller here is based on zero-level universal combination model as formular 1, namely one-level universal combination model when \( k=0.5 \).

\[
C(x,y,h) = \text{ite} \Gamma^c((x^c + y^c - e^c)^m) \mid x + y < 2e; \\
1 - \Gamma^e((1-x)^m + (1-y)^m - (1-e)^m) \mid x + y > 2e, \quad \epsilon
\] (1)

In the applications, the system variables always change in some interval \([a,b]\). The transform of variables from interval \([a,b]\) to unit interval will lead to information loss. So, the reasoning model can be the zero-level universal combination model \(GC^c\) in interval \([a,b]\), which satisfies the mapping \([a,b] \times [a,b] \rightarrow [a,b]\) shown as formular 2.

\[
GC^c(x,y,h) = \text{ite} \min(\tilde{e},(b-a)\max(0,((x-a)^m + (y-a)^m - \tilde{e}(b-a))^m + a)) \mid x + y < 2\tilde{e}; b + a \\
\text{max}(0,((x-a)^m + (y-a)^m - (b-a)^m))^m + a) \mid x + y > 2\tilde{e}; \epsilon
\] (2)

In the above formulars, \(m=(3-4h)/(4h(1-h))\), \(h \in [0,1]\), \(\tilde{e}, \epsilon \in [a,b]\), \(\tilde{e} = GN(\tilde{e})\), \(\Gamma^c[x] = \text{ite} \epsilon \mid x > \epsilon; 0 \mid x < 0; x\). \(GN\) is the zero-level universal Not model in interval \([a,b]\). And \(GN(x)=b-a-x\). When \(h=0, 0.25, 0.5, 0.75\) and \(h=1\), the three-dimension figures of zero-level universal combination model in interval \([a,b]\) are shown in Fig.1. In Fig.1, \(z = GC^c(x,y,h)\), \(x\) and \(y\) are the inputs of universal combination model \(GC^c\) in interval \([-5,5]\), \(h\) is the general correlation coefficient.

![Figure 1. Three-dimension figures of zero-level universal combination model in interval \([-5,5]\)](image1.png)

In real applications, by adding the weight factors to the combination model, the variables of model will have different importances that make control effect better. Formular 3 shows the linear weighted zero-level universal combination operation model in interval \([a,b]\). When \(h=0, 0.25, 0.5, 0.75\) and \(h=1\), its three-dimension figures are show in Fig.2. In Fig.2, \(z = GCV^c(x,y,h,a,b)\), \(x\) and \(y\) are the inputs of \(GCV^c\) in interval \([-5,5]\), \(h\) is the general correlation coefficient, weight factors \(\alpha = 0.6, \beta = 0.4\).

\[
GCV^c(x,y,h,a,b) = GC^c(ax,by,h) = GC^c(x',y',h) \mid x', y' \in [0,1], h \in [0,1]
\] (3)

III. THE STRUCTURE AND DESIGN OF FLEXIBLE UNIVERSAL LOGICS CONTROL SYSTEM

The flexible universal logics control is a kind of computer autocontrol based on universal logics. It belongs to nonlinear control, feedback control, closed-loop control and intelligent control from the different aspects.

A. The structure of universal logics control system

The universal logics control system shown as Fig.3 is composed of universal logics controller, I/O interface, controlled object, detection device and executive unit. Universal logics controller is the core part of the whole system. It consists of the obtaining input module, universalizing input module, structure choosing module, unequal weights parameter optimizing module, decision-making module and de-universalizing output module.

![Figure 3. The structure of the control system](image3.png)

B. The principle of universal logics control

The main procedure of universal logics control is as the following:

1. By interrupting to get the controlled variables, the controller compare them to the expectations and obtain the inputs of universal logics controller, such as the error, the rate of error.
2. By universalizing the inputs in real work domain, the correlated variables in the interval \([a,b]\) are obtained.
3. Based on universal combination model, the decision-making module get the control variable \(u^c\) in \([a,b]\).
4. By de-universalizing \(u\), the real control variable \(u\) in work domain is obtained.
5. The control variable \(u\) is transformed by D/A unit and then sent to executive unit to control the object in this control circle.
6. Jump Step.1, and go on.
The decision-making module is the core part of the controller. The structure choosing module determines the inside structure of decision-making module offline. And the unequal weights parameter optimizing module optimizes the control parameters of universal logics controller based on genetic algorithm offline. The estimate function in genetic algorithm reflects that the different control sub-targets have different control priorities and different control systems have different control demand. For example, some system puts more demanding on control rapidity and the other puts more demanding on control stability.

The number of input variables is called the dimension of universal logics controller. Shown as Fig.4-a, there are two inputs in two-dimension controller, so the decision-making module consists of one universal combination model and these two inputs are universalized as the inputs of the universal combination model. Two-dimension controller is always to be used to implement the sub-control-target in multi-dimension control system.

There are three inputs in the three-dimension controller shown as Fig.4-b. The two tightly-coupled inputs are as the inputs of the first universal combination model. And its output and the third input are as the inputs of the second universal combination model. Otherwise, if the coupling degrees between any two inputs are similar, the inputs of the first combination model can be chosen at random.

There are four inputs in the four-dimension controller. The structure shown as Fig.4-c is fit for the situation that the two inputs are tightly-coupled and the other inputs are loosely-coupled. The structure in Fig.4-d is fit for the situation that two pairs of inputs are tightly-coupled and the outputs of two combination models are also tightly-coupled. It can be applied to control the system which can be decomposed into two tightly-coupled sub-systems.

The high-dimension controller can be designed just like four-dimension controller. The decision-making module is constituted by many universal combination models in series or parallel. The inputs of each combination model are usually tightly-coupled.

Because the interval [0,1] is too small for the real system variables and a lot of useful information may be ignored when they are universalized, the universal combination model in flexible controller is zero-level or linear weighted zero-level universal combination model in interval [a,b]. The controller using the latter could control the object intensively. If the controlled object could be decomposed into many coupled sub-system, its flexible universal logics controller has three forms.

1) The sub-controller is based on zero-level universal combination model in interval [a,b]. The outputs of each sub-controller are integrated by linear weighted sum module. This kind of controller is called ULC_I (Universal logics controller_I).

2) The sub-controller is based on linear weighted zero-level universal combination model in interval [a,b]. The outputs of each sub-controller are integrated by linear weighted sum module. This kind of controller is called ULC_II.

3) The sub-controller is based on zero-level universal combination model in interval [a,b]. The outputs of each sub-controller are integrated by linear weighted zero-level universal combination model in interval [a,b]. This kind of controller is called ULC_III.

Based on theoretical analysis, the universal logics controller is fit to control the complex system. But for the system with more simple internal structure, universal controller can also control it effectively.

The control to the typical linear system

For the simple system with the transfer function shown as Formula 4, the structure of controller is designed as shown in Fig.4-b. And the decision-making module is based on zero-level universal combination model in interval [a,b]. After being optimized by the unequal weights parameter optimizing module, the control parameters are obtained. The two universalization factors, de-universalization factor, general correlation coefficient of universal combination model 1 are 6.6667, 14.1176, 14.6667 and 0.5059. The
corresponding parameters of universal combination model 2 are 19.8039, 26.2745, 0.0784 and 0.8000. When the initial state of system is [0.5 -0.3 0.2], the variation curves of each variable are shown as Fig.5. In Fig.5, $x_1$, $x_2$ and $x_3$ are the three system state variables, and the horizontal axis $t$ denotes control time.

$$G(x) = (2x^2 + 9x + 1)/(x^2 + x^2 + 4x + 4)$$ (4)

![Figure 5. The variation curves of each variable for three-order system](image)

**B. The control to the triple inverted pendulum**

The inverted pendulum is a typical nonlinear, multi-variable, strong-coupling and naturally unstable complicated controlled system. It is a classical experiment platform for verifying control theories and methods. Given a triple inverted pendulum system, its physical parameters are shown in Table.1. Its controller is designed as ULC_I in interval [-8,8]. The four universal combination models are the four sub-controllers for the car, the first pendulum, the second pendulum and the third pendulum respectively.

**TABLE I. THE PHYSIC PARAMETERS OF THE TRIPLE INVERTED PENDULUM**

<table>
<thead>
<tr>
<th>Physical meaning</th>
<th>Value</th>
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<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>car’s mass(kg)</td>
<td>0.924</td>
<td>the first pendulum’s mass(kg)</td>
<td>0.01762</td>
</tr>
<tr>
<td>the second pendulum’s mass(kg)</td>
<td>0.04196</td>
<td>the third pendulum’s mass(kg)</td>
<td>0.07312</td>
</tr>
<tr>
<td>mass of module between pendulum i and pendulum i+1(kg) (i=1,2)</td>
<td>0.18582</td>
<td>distance from centroid of the first pendulum to toaxis of rotation (m)</td>
<td>0.075</td>
</tr>
<tr>
<td>distance from centroid of the second pendulum to toaxis of rotation (m)</td>
<td>0.09975</td>
<td>distance from centroid of the third pendulum to toaxis of rotation (m)</td>
<td>0.19975</td>
</tr>
<tr>
<td>moment of inertia for the first pendulum (kg*m$^2$)</td>
<td>3.3038e-5</td>
<td>moment of inertia for the second pendulum (kg*m$^2$)</td>
<td>1.3917e-4</td>
</tr>
<tr>
<td>moment of inertia for the third pendulum (kg*m$^2$)</td>
<td>9.7250e-4</td>
<td>friction coefficient between car and railway (N*s/m)</td>
<td>0.1</td>
</tr>
<tr>
<td>friction of resistance for pendulum i (N<em>s</em>m)</td>
<td>0.00003</td>
<td>max distance of railway(m)</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Based on the unequal weights parameter optimizing module, the control parameters are obtained as the following. The universalization factors, the de-universalization factor and the general correlation coefficient of the car sub-controller, the first pendulum sub-controller, the second pendulum sub-controller and the third pendulum sub-controller are 11.1765, 21.8824, 2.0039, 0.5090; 40, 2.0039, 0.7490; 88.1333, 9.7529; 86.1176, 24.7333, 0.7490 and 0.9255 respectively. And the weighted coefficients of four sub-system are 0.302, -0.0588, 0.2157 and -0.5451 respectively. The control effect in 10 seconds is shown as Fig.6.

![Figure 6. The control effect for triple inverted pendulum](image)

In each sub-figure of Fig.6, the horizontal axis $t$ denote control time, and the vertical axes denote the car’s displacement, the car’s rate, the first pendulum’s angle and angle rate, the second pendulum’s angle and angle rate and the third pendulum’s angle and angle rate respectively. And in each sub-figure, the state variable gets to the balance place successfully.

**V. CONCLUSION**

The flexibilization problem for the intelligent control model is studied here. And a flexible universal logics intelligent control method is proposed. This control model is based on universal combination operation model and has
three typical parameters $e$, $h$ and $k$. These three parameters denote the threshold of decision-making, the relationship between the controlled variables and the measurement error respectively. They make the flexible universal logics controller more suitable for the real control problem. The successful applications to the typical linear system and nonlinear complex system prove the validity of the controller.

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