A Reconfigurable Fuzzy Inference System*

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[ABSTRACT] :

According to a developed programmable fuzzy controller and a new fuzzy reasoning theory---TVFI Theory, this paper put forward the idea of a reconfigurable Fuzzy Inference System.

Taking advantage of this kind of reconfigurable system, we can deal with different application problems conveniently, for example, processing of different types of knowledge, different reasoning operators etc.. So, it makes fuzzy inference system possess different functions, and makes its framework more perfect, and its flexibility increased.

[Keywords] : Fuzzy Inference, Fuzzy Logic Hardware, Dynamic Knowledge

I. Introduction

Recently, to implement a system supported with fuzzy sets theory on hardware is considered as one key how to promote fuzzy sets theory and its applications into a higher level so that we can deal with fuzzy information more effectively and quickly [1].

Supported by Chinese National Science Foundation, we have developed several prototypes of Fuzzy Inference Machine (abbreviated as FIM) [2] and have applied them into a practical production process of plastic film. And based on that practical application, a special fuzzy controller for plastic film production has developed [3].

However, in the situation of practical application, we deeply felt that for some applicational fields (e.g., the field of automatic control), it is effective enough to adopt a unchangable reasoning machinism to deal with fuzzy information in these systems; but for others (e.g., expert system or model recognition etc.), we must choose different reasoning machinism to deal with fuzzy information according to the different objects and different conditions.

Hence, we think, as a generalized fuzzy logic system, it had better have a reconfigurable structure, in order to meet the needs of practical applications at different fileds. Here, the meaninng of word " a reconfigurable structure " is that a fuzzy logic system have different reasoning machinism, roughly including : different methods of rule choice and different methods of rule matching, different number of reasoninng layer (or different number of reasoning chains), different reasoning operators, and so on. [4, 5, 6, 7, 10, 11].

In this paper, we mainly pay attention to how to make a fuzzy system have different reasoning operators and the ability of handling different types of knowledge(rule) based on TVFI theory. Such a fuzzy system endowed with different reasoning machinism may be named as Reconfigurable Fuzzy Inference System (abbreviated as RFIS) in this paper. We preliminarily discuss the implementation methods on hardware of such a fuzzy system. It is obvious that RFIS has more perfect structure than FIM with fixed structure and reasoning mechinism, and more flexible than the latter.

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The paper is organized as follows: firstly, we abstractly discribe the principle of TVFI theory proposed by Professor Wang, et al[8] for fuzzy reasoning. Also, secondly, the structure of a developed programmable fuzzy controller is simply introduced. On the base of section 2 and section 3, we give the constructure of RFIS and the concept of dynamic knowledge, and discuss the realization of RFIS on hardware at section 4. Finally, a simple conclusion is gived.

II. TVFI Theory

TVFI theory(Truth Valued Flow Inference Theory) is a theory framework about fuzzy inference proposed by Professor Wang, et al[8]. Its main idea is that TVFI theory naturally consider the reasoning process as a passing process in which the truth-value flows along the reasoning channel.

Let's consider a fuzzy implication formula:

$$P \dashrightarrow Q \qquad (1)$$

$$P \in F(U), \quad Q \in F(V)$$

where, U, V is a universe of discourse respectively.

It can be regarded as a reasoning channel. P is the head of the channel, and Q is the tail of the channel. If the truth value flows from the head to the tail, a reasoning process will have been implemented.

Obviously, several implication formulas form a family of reasoning channel. Suppose:

$$Pi \dashrightarrow Qi \qquad (i=1,2,\ldots,n) \qquad (2)$$

$$Pi \in F(U), \quad Qi \in F(V)$$

For a given fact P', TVFI theory seperates all fuzzy reasoning process into three steps:

1. Comparing the fact P' with each head Pi and get a truth value. Here, the computing method of truth-value is to calculate so-called the degree of nearness between P' and Pi: i.e.:

$$Ti = \text{nearness}(P', Pi) \qquad (3)$$

$$i = 1,2,\ldots,n.$$

It is the first stage of TVFI. It also be called the front reasoning stage of TVFI.

2. The flowing step of truth value along each reasoning channel. Each truth value is carried to the tail of channel through its reasoning channel respectively, then the truth value in the tail is obtained:

$$T(Qi) = Ti \qquad (i = 1,2,\ldots,n) \qquad (4)$$

In fact, T(Qi) is the result of fuzzy reasoning.

3. The rear treating step of truth value.

According to practical applications, Equ.(4) can be transformed into fuzzy or definite decision:

$$d = d(T1, Q1, \ldots, Tn, Qn)$$

The transformation method may be various. For example:

$$d(V) = \bigcup_{i=1}^{n} (Ti \cap Qi(v)) \qquad (5)$$

or

$$d(V) = \bigcap_{i=1}^{n} (Ti \cap Qi(v)) \qquad (6)$$

or

$$d(V) = \sum_{i=1}^{n} Ti * Qi \qquad (7)$$

Where, Qi in Eq. (7) denotes the midpoint of obtained peak value.

What we introduced above is the main idea of TVFI theory. Certainly, the implication shown above only is a simple case, that is to say, the reasoning channel is very simple. For more complicated implications, all the reasoning processe can also be seperated into three steps similarly. However, since the reasoning channels become more complicated, the truth value flowing process in step 2 will include the operating process of truth value. The details of TVFI theory can be seen in [8].

III. About A Programmable Fuzzy Controller

A programmable fuzzy controller is a kind of Fuzzy Inference Machine which is implemented on hardware based on TVFI theory [14]. Its reasoning speed can reach up to 20,000,00- Flips (Fuzzy Logical Inference per second), It has merits of stronger function, high-speed, smaller size, lower production cost, and so on.

According to TVFI Theory, the system architecture of this machine is shown in Fig. 1.

That is to say, the system is mainly made up of following four parts:

1. T-Generator (Truth-value Generator)
2. TVFI Array
3. Output Model
4. Programmable Device(PD)

Actually, part 1, part 2 and part 3 finish the three processes (or called three steps) of TVFI theory. Part 4 is a programmming device (abbreviated as PD) which is used to program and supervise the system. Such a configuration of the system, we think, takes advantage of not only the contemporary digital computer, but that FIM can deal with fuzzy information rapidly and effectively. So, to some extent, some defects of contemporary digital computer can be complemented. It should be an essential character of fuzzy inference system.

IV. A Reconfigurable Fuzzy Inference System (RFIS)

According to the discussion of above paragraphs, we think that it is easy to realize RFIS on the basis of TVFI Theory.

From Fig. 1, we know that if we can make the three models reconfigurable in Fig. 1, i.e,

T-Generator, TVFI Array, Output Model, then we can build RFIS, Shown in Fig. 2.

So, to discuss RFIS based on TVFI Theory is to discuss the configuration of CT-G, CTVFI and CT/U.

We will discribe such three parts as follows:

1. A Reconfigurable Truth Value Generator (CT-G)

The founction of T-Generator in Fig. 1 is to generate the truth value in the head of each reasoning channel. Hence, the meaning of CT-G is to generate truth value in different ways according to different requirements. The formula (3) introduced a method of obtaining truth value (i.e. the method of the degree of nearness), but we can use other methods to obtain truth value for example, the method of truth value set [9] etc. Because of the limitation at the length of the paper, we are not going to discuss the problems of its implementation on hardware in detail.

2. A Reconfigurable TVFI Array (CTVFI)

2.1 A Reconfigurable operating array of truth value (CTVC Array)

The usual TVFI Array (e.g. in Fig. 1) is made of two parts: rules choosing array and truth value operating array, shown in Fig. 3. The operation method of truth value in TVFI is only one, i.e. Min-Max operation. But, CTVFI requires different methods of rule choice and different operating methods of truth value.

Different rule choosing methods can be conveniently realized by a digital computer(or a digital processor) in Fig. 2, so we needn't discuss it. We are going to discuss the realization of different operating methods of truth value.

Here, different operating methods of truth value have two meanings: The first one is to use different reasoning operators when calculating truth value, and the different mathematical definitions of conjunctions "AND" and "ELSE" in fuzzy rules [10, 14]; The second one is to choose corresponding operating methods on basis of different generating methods of Truth-Value.

A Reconfigurable Truth-Value Operating Arrays can be made of so-called CTVC Units. Every CTVC Unit has the reconfigurable function. We give its constructure in Fig. 4. [11, 12].

This is a three-inputs and one-output CTVC Unit, where S1 and S2 are actually the information which come from the supervising model of RFIS System (e.g. a digital computer in Fig. 2). So, a reconfigurable truth value operating method has been realized.

Fig. 5 is an example of CTVC Array which consists of 4 CTVC units such as shown in Fig. 4 and one Maxgate whose function is to find out the maximum output of 4 CTVC units.

2.2 The processing of dynamic knowledge based on CTVFI.

We have pointed out that for different practical applications, there are different rule forms, or called different describing forms of knowledge.

In an industrial dynamic environment, since the described object is dynamic, the knowledge describing of such an object must be dynamic too. That is to say, the factor of time must be considered in the expression of dynamic knowledge for the dynamic processes. We have following definition:

DEFINITION.1. Given following rules[13]:

If x1 is A_1 and x2 is B_1 and x3 is C_1 then y is D_{111} after $f_{111}(t)$;
else
.....
else
If x1 is A_n and x2 is B_m and x3 is C_l then y is D_{nml} after $f_{nml}(t)$;

(8)

then we call Equ.(8) an expression of dynamic knowledge.

where, $f_{ijk}(t)$ (i = 1, 2,..., n; j = 1,2,...,m; k = 1, 2,..., l) are the function of time t.
$A_i \in F(U)$, $B_j \in F(V)$, $C_k \in F(W)$, $D_{ijk} \in F(T)$
U, V, W, T are universes of discourse respectively
$x1 \in U$, $x2 \in V$, $x3 \in W$, $y \in T$

According to different application objects, $f_{ijk}(t)$ may be a constant, or may be time-varying. If $f_{ijk}(t)$ is a time constant(e.g., 2 second) for any i, j, k but for $f_{ijk}(t)=0$, for all i, j, k, we call what the formula (8) expressed a kind of time-constant dynamic knowledge, otherwise we call it a kind of time-varying dynamic knowledge.

Corresponding to definition 1, if $f_{ijk}(t) = 0$ for all i, j, k, we call what the formula (8) expressed a kind of static knowledge. It just is the rules' form which we usually use.

Expressing and dealing with dynamic knowledge is a special research topic. We have only given a simple expression form here [13].

Taking advantage of TVFI Theory, we can deal with such dynamic knowledge as expressed in formula (8) conveniently.

We have already pointed out that TVFI Theory considers the reasoning process as the process that truth value flow along the reasoning channel. But we didn't consider the time the flowing of the truth value takes (but not the response time of the circuit). That is to say, the flowing of truth value in reasoning channel which we considered above takes no time. It is passed through the reasoning channel instantaneously. In this case, we consider what the reasoning process expressed as a kind of static knowledge.

By use of this concept, if we set up a device of time-delaying link or called Time-Valve in a reasoning channel of truth value, then the flowing of truth value is not finished instantaneously. A truth value flows to the channel tail along the reasoning channel according to the time constant (or time founction) which is set up by the Time Valve. So, we think that the reasoning process has just rightly expressed a kind of dynamic knowledge such as formula (8). Obviously, if the time constant of Tmie-Valve is set as zero, in this case, what the reasoning process expressed is a kind of static knowledge.

The reasoning channel with Time Valve can be described by Fig.6

In Fig.2, we can set up time constant (or time function) to Time-Valve through DB&AB by the computer. So, we can nimbly deal with two kinds of different knowledge (i.e. static and dynamic knowledge). Dynamic knowledge includes time-constant dynamic knowledge and time-varying dynamic knowledge. Generally speaking, the position of time-valve should be arbitrary, but in order to save hardware device, and for convenience, we think that it may be reasonable to set the time-valve on the last part of CTVFI Array.

According to the discussion of above 2.1 and 2.2, we can give the configuration of

reconfigurable TVFI Array as shown in Fig.7.

3. A Reconfigrable Output Model(CT/U).

As we have known, the function of CT/U is to adopt different defuzzification method according to the needs of practical problems. It is easy to implement CT/U, so we wouldn't discuss it in detail.

V. Conclusions

Fuzzy Inference Machine would be considered as one of the first research steps of a new generation computer, i.e., intelligent computer. We think, the research of reconfigurable Fuzzy Inference System may be an important step to reach above goal. Certainly, what we have put forward in this paper isn't perfect or complete yet, because the intent of reconfigurable system is very extensive. So, we have to do more advanced research work.

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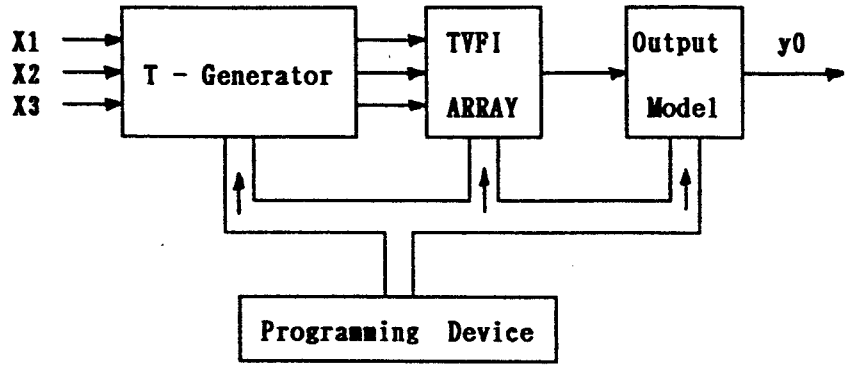
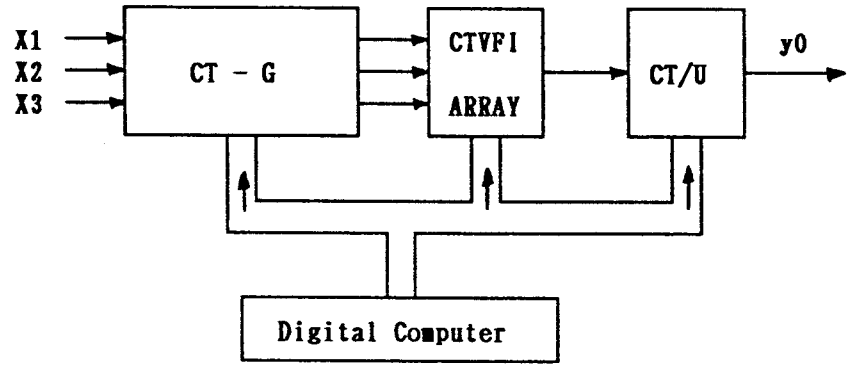
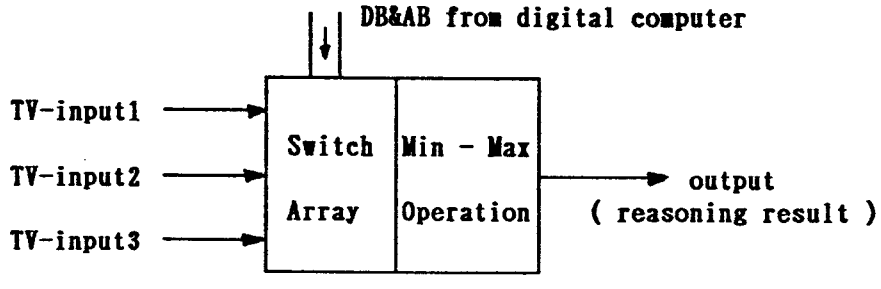


Fig. 1 A block diagram of the programmable fuzzy controller



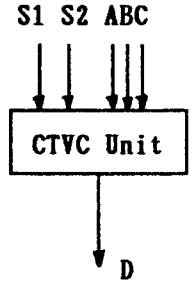
where, CT-G : a reconfigurable truth value generator
CTVFI ARRAY : a reconfigurable TVFI ARRAY
X1, X2, X3 : three inputs of RFIS
y0 : output of RFIS

Fig. 2 An illustration of RFIS



where, TV-input1~3 : three truth value input channels from three truth value generators
Switch Array : used to select different rules
Min-Max Operation : used to operate truth values in Min-Max method

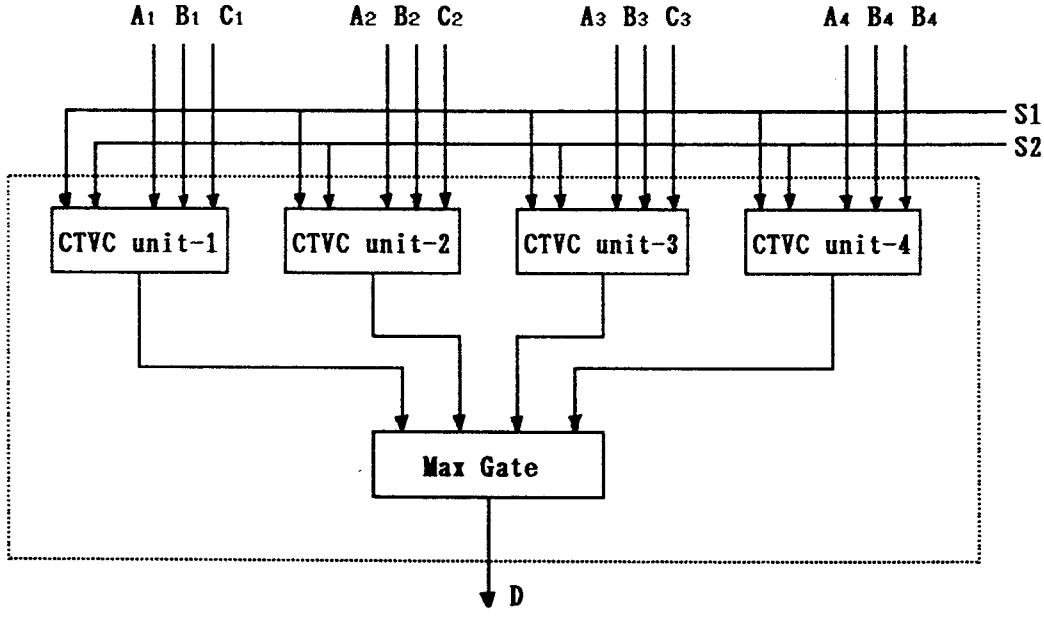
Fig. 3 A block diagram of TVFI Array



S2	S1	D(y)
0	0	min [A(x1), B(x2), C(x3)]
0	1	max [A(x1), B(x2), C(x3)]
1	0	A(x1) * B(x2) * C(x3)
1	1	A(x1) ∧ B(x2) ∧ C(x3)

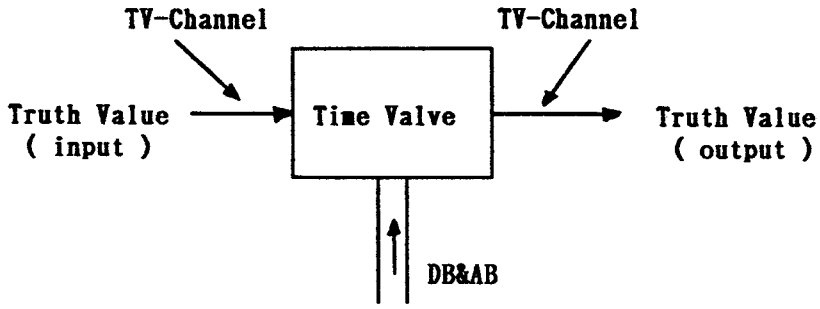
where, $A \in F(U)$, $B \in F(V)$, $C \in F(W)$, $D \in F(T)$
U, V, W, T are universes of discourse respectively
$x1 \in U$, $x2 \in V$, $x3 \in W$, $y \in T$

Fig. 4 An illustration of a CTVC Unit



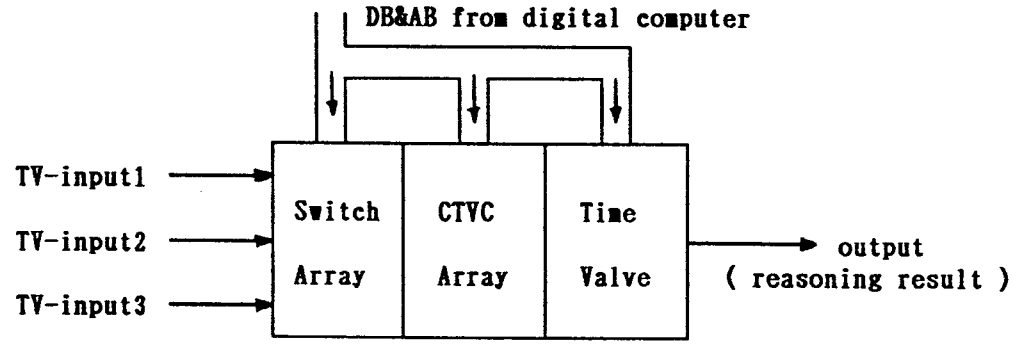
where, $A_i \in F(U)$, $B_j \in F(V)$, $C_k \in F(W)$, $D \in F(T)$
U, V, W, T are universes of discourse respectively
$i = 1, 2, 3, 4$; $j = 1, 2, 3, 4$, $k = 1, 2, 3, 4$;

Fig. 5 an illustration of CTVC Array



where, TV-Channel means the Truth Value Channel

Fig. 6 An illustration of a reasoning channel with Time-Valve



where, TV-input1~3 : three truth value input channels from three truth value generators
Switch Array : used to select different rules
CTVC Array : used to finish the operating of truth values with different methods
Time Valve : used to handle static & dynamic knowledge

Fig. 7 An illustration of CTVPI-Array