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Fuzzy Time Control Modeling Of Discrete Event Systems

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Abstract—**Linguistic modeling of complex irregular systems is helpful for the generation of decision making controls. In the various existing Fuzzy models, proposed by Mamdani, Sugeno, and Tsukamoto, the concepts of the set of membership functions and different Fuzzy logic rules to reason about data were addressed. The time control issues were not discussed in these models. In this paper, a new model is proposed with initial membership functions of the fuzzy model and the linguistic fuzzy rules with time control membership function of the binary valued outputs instead of crisp values. The system is named fuzzy logic time control system (FLTCS) with the proposed timing approach and implemented with discrete event system DEVS.**

Index Terms—**Irregular systems, Fuzzy models, Time control issues, Time control membership function, Fuzzy logic time control systems and discrete event system.**

I. INTRODUCTION

The fuzzy logic and fuzzy set theory deal with the non-probabilistic uncertainties issues suggested by zadeh in 1965 [1]. These concepts are evolved in various disciplines, such as calculus of fuzzy if-then rules, fuzzy reasoning, fuzzy inference systems, fuzzy modeling, fuzzy graphs and fuzzy topology. Fuzzy models are used in various disciplines such as automatic control, decision making expert systems, consumer electronics and computer vision etc [2],[3],[4].

The fuzzy control is based on the theory of fuzzy sets and fuzzy logic. Mamdani's pioneering work motivated to persue the research field of control systems in fuzzy modeling [5].

Previously number of fuzzy inference system and defuzzification techniques were reported [6] and [7]. These systems/techniques had less computational overhead and were useful to obtain crisp output [6] and [7]. Indeed existing fuzzy models have addressed the way to reason using membership function and fuzzy rule [8], [9], [10] and [11], but did not take into account the time dependency of output(s) in control systems. The crisp output value was based on linguistic rules applied in inference engine and defuzzification techniques [12].

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In this paper time control issue for binary control output with logic 0 or logic 1 for a specific determined time is proposed. The output state and its time are based on the linguistic rules applied for this new system. We proposed the membership function for the timing of output state. The output crisp values determined by defuzzifier are compared with certain values and changed into binary form for logic 1 or logic 0. These logic levels can be used as the control outputs to activate the plant components (or valves) ON or OFF for a specific time determined by the linguistic values of inputs and fuzzy inference system. The new time control fuzzy system is called fuzzy logic time control system (FLTCS)[13].A time control model is presented for fuzzy logic system and implementation techniques are discussed.

The arrangement of this paper is as follows. In section 2, Fundamentals of Fuzzy Set, Membership Function and Fuzzy Mathematics are given. In section 3, Fuzzy reasoning and Fuzzy time control modeling are explained. In Section 4, Fuzzy Logic Controller, and Fuzzy Discrete Event Control System are explained. Section 5 explains Modeling and implementation, Fuzzy Time Control System with DEVS and section 6 concludes this paper and gives future directions.

II. FUNDAMENTALS OF FUZZY SET, MEMBERSHIP FUNCTION AND FUZZY MATHEMATICS

A fuzzy set is a set without crisp boundary and characterized by membership functions. For a given datum x, a fuzzy set A contains x with a degree of membership $\mu_A(x)$, where $\mu_A(x)$ can take any value in the domain [0,1]. Fuzzy sets A,B,C,……… are given descriptive names such as Linguistic variables:
LOW, MEDIUM, HIGH Or SLOW, FAST, VERY FAST
Or SLOW, MEDIUM, FAST Or NEGATIVE BIG (NG), NEGATIVE SMALL (NS), ZERO (Z), POSITIVE SMALL (PS) , POSITIVE BIG (PG).

The MFs reflects the similarity between values of datum and contextual meaning of linguistic variables. For example, membership function $\mu_{SLOW}(x)$ is used to reflect the similarity between values of x and a contextual meaning of **SLOW**.

The three fundamental Boolean logic operations, intersection $\wedge$, Union $\vee$ and complement have fuzzy counterparts defined by extension of the rules of Boolean logic.

The fundamental concepts [12], [14], [1] of Fuzzy Mathematics are given as follows:
If X is a collection of objects denoted by x, then a fuzzy set A in X is defined as $A = \{ (X, \mu_A(x)) / x \in X\}$

$\mu_A(x)$ is the MF of x in A. The MF maps each element of X to a continuous.

Membership values or Ms grade between 0 and 1.

$A = \sum_{x_i \in x} \mu_A(x_i)/ x_i$,if X is discrete

$A = \int_x \mu_A(x)/ x$,if X is continuous.

Let $X = \{ x_1, x_2, x_3, ... \}$ and $\mu_A(x_1), \mu_A(x_2), \mu_A(x_3)$ … are the membership functions corresponding to $x_1, x_2, x_3, ...$

The fuzzy set with discrete x is

$A = \{ (x_1, \mu_A(x_1)) ,(x_2, \mu_A(x_2)), (x_3, \mu_A(x_3)), …\}$

Or

$A = \mu_A(x_1)/ x_1 + \mu_A(x_2) /x_2 + \mu_A(x_3) / x_3 +…$

Containment or Subset of fuzzy set

$A \subseteq B \Leftrightarrow \mu_A(x) \le \mu_B(x)$

The union of two fuzzy sets A and B is a fuzzy set C , written as :

$C = A \cup B$ or $C = A$ or B or $C = A \vee B$

Their MF's are also related as:

$\mu_c(x) = \max(\mu_A(x), \mu_B(x)) = \mu_A(x) \vee \mu_B(x)$

'max' is '$\vee$' or 'OR'

The intersection of two fuzzy sets A and B is also a fuzzy set C , written as :

$C = A \cap B$ = A AND B=$A \wedge B$.

Their MFs are also related as:

$\mu_c(x) = \min(\mu_A(x), \mu_B(x)) = \mu_A(x) \wedge \mu_B(x)$

Here 'min' is '$\wedge$' , or 'AND'.

Complement of fuzzy set A is $\bar{A}$ or ($\neg$A or NOT A) MF of $\bar{A}$ is

$\mu_{\bar{A}}(x) = 1 - \mu_A(x)$

For $\mu_{A \cap B}(x)$, the MF of $A \cap B$ and $\mu_{A \cap B}(x) = \mu_A(x). \mu_B(x)$ and for

$\mu_{A \cup B}(x)$, the MF of $A \cup B$

$\mu_{A \cup B}(x) = \mu_A(x) + \mu_B(x) - \mu_A(x) \mu_B(x)$

A fuzzy if-then rule (fuzzy rule, fuzzy implication or fuzzy conditional statement) is if **x is A then y is B**, where A and B are linguistic values defined by fuzzy sets.

"x is A" is called **antecedent or premise**.

"y is B" is called the **consequence or conclusion.**

Fuzzy relation $R = A \rightarrow B = A \times B$

This suggests that a fuzzy if-then rule be defined as binary fuzzy relation R on the product space $X \times Y$.

Also $(x, y) \in X \times Y$ is associated with two dimensional MF $\mu_R(x, y)$.

$R = A \rightarrow B = A \times B = \int_{x \times y} \mu_A(x) * \mu_B(y) / (x, y)$

Where $*$ is fuzzy AND

Also $R = A \rightarrow B = \neg A \cup B = \neg A \cup (A \cap B)$

$= (\neg A \cap \neg B) \cup B$[15]

III.FUZZY REASONING AND FUZZY TIME CONTROL MODELING

An appropriate or fuzzy reasoning is an inference procedure used to derive conclusion from a set of fuzzy if – then rules with one or more conditions. The essential rational behind fuzzy reasoning is compositional rule of inference [16], [17]. If A is a fuzzy set of X and F is a fuzzy relation on X×Y then fuzzy set B of Y can be determined. Let μ_A, $\mu_{C(A)}$, μ_B and μ_F be the MFs of A , C (A) , B and F respectively. Where C (A) is the extension with base A. We can expand the domain of A from X to X ×Y to get C (A).

$\mu_{C(A)}(x, y) = \mu_A(x)$

Then $\mu_{C(A) \cap F}(x, y) = \min[\mu_{C(A)}(x, y), \mu_F(x, y)]$

$= \min[\mu_A(x), \mu_F(x, y)]$.

By projecting $C(A) \cap F$ onto the y axis, we get

$\mu_B(y) = \max_x \min[\mu_A(x), \mu_F(x, y)]$

$$= \vee_x [\mu_A(x) \wedge \mu_F(x, y)] \quad (1)$$

This formula is referred to as max – min composition and B is represented as,

$$B = A \text{ o } F \quad (2)$$

Where 'o' is composition operator.

If we choose product for fuzzy AND and max for fuzzy OR, then we have

max – min product composition.

$\mu_B(y) = V_x [\mu_A(x), \mu_F(x, y)]$.

The basic rule of inference in two valued logic is modus ponens, according to which we can infer the truth of a proposition B from the truth of A and the implication $A \rightarrow B$. [2]

The concept of modus ponens is as follows:

A. *Fuzzy Reasoning with output variable time Control*

For case I Single rule with single antecedent.

Premise 1 (fact) x is A'

Premise 2 (rule) if x is A then y is B.

Consequence (conclusion) y is B' for time t.

$\mu_A(x_1), \mu_A(x_2), \mu_A(x_3)$……… are the Membership values Corresponding to members, x_1, x_2, x_3,… and Fuzzy set $A=\{(x_1, \mu_A(x_1)), (x_2, \mu_A(x_2)),… \}$

Membership values for the outputs members y_1, y_2, y_3 … are $\mu_B(y_1,t_1)$, $\mu_B(y_2,t_2)$, $\mu_B(y_3,t_3)$,.

and

$B = \{[y_1, \mu_B(y_1,t_1)] , [y_2 , \mu_B(y_2,t_2)], ...\}$

Here A = f(x) and B = f(y,t)

Where x is input and y is output variable.

$\mu_{B'}(y, t) = \max_x \min[\mu_{A'}(x), \mu_R(x, y, t)]$

$$= \vee_x [\mu_{A'}(x) \wedge \mu_R(x, y, t)] \quad (3)$$

$\mu_{B'}(y) \wedge \mu_{B'}(t) = \vee_x [\mu_{A'}(x) \wedge \mu_A(x) \wedge \mu_B(y) \wedge \mu_T(t)]$.

$= [\vee_x \mu_{A'}(x) \wedge \mu_A(x)] \wedge \mu_B(y) \wedge \mu_T(t)$.

$$\mu_{B'}(y) \wedge \mu_B(t) = w \wedge \mu_B(y) \wedge \mu_T(t) \quad (4)$$

This shows that dependence of output time control function on the weight input function, output MF and time MF corresponding to the output function. Where w is the degree of match between A and A' and fuzzy set $T = \{ [t_1, \mu_T(t_1)], [t_2, \mu_T(t_2)], [t_3, \mu_T(t_3)], …………\}$ timing set $t = \{ t_1, t_2, t_3, ………\}$ is the set for values of time corresponding to the output values, y_1, y_2, y_3 ,………, the members of Y.

For case II which is about single rule with two antecedents:

Premise 1 (fact) : x is A' and y is B'

Premise 2 (rule) : if x is A and y is B then z is C

Consequence (conclusion) : z is C' for time t.

Where x and y are inputs and z is the output.

$C' = (A' \times B') o(A \times B \rightarrow C)$

Where A = f (x), B = f (y), and C = f (z ,t).

$\mu_{C'}(z,t) = \vee_{x,y}[\mu_{A'}(x) \wedge \mu_{B'}(y)] \wedge [\mu_A(x) \wedge \mu_B(y) \wedge \mu_C(z) \wedge \mu_T(t)]$ (5)

$\mu_{C'}(z,t) = \mu_{C'}(z) \wedge \mu_{C'}(t)$

$= \vee_{x,y}\{[\mu_{A'}(x) \wedge \mu_{B'}(y) \wedge \mu_A(x) \wedge \mu_B(y)] \wedge \mu_C(z) \wedge \mu_T(t)\}$

$= \{\vee_x[\mu_{A'}(x) \wedge \mu_A(x)]\} \wedge \{V_y[\mu_{B'}(y) \wedge \mu_B(y)]\} \wedge \mu_C(z) \wedge \mu_T(t)$

$\mu_{C'}(z) \wedge \mu_{C'}(t) = w_1 \wedge w_2 \wedge \mu_C(z) \wedge \mu_T(t)$ (6)

This shows the dependence of output time control value on the input weighted functions and output value function.

For case III which is almost multiple rules with multiple antecedents.

Premise 1 (fact): x is A' and y is B'
Premise 2 (rule): if x is A_1 and y is B_1 then z is C_1
Premise 3 (rule2): if x is A_2 and y is B_2 then z is C_2
Consequence (condition): z is C' for time t.

Let $R_1 = A_1 \times B_1 \rightarrow C_1$ and $R_2 = A_2 \times B_2 \rightarrow C_2$.

As max-min composition operator "o" is distributive over $\cup$ operator, so

$C' = (A' \times B')\ o\ (R_1 \cup R_2)$

$= [(A' \times B')\ o\ R_1] \cup [(A' \times B')\ o\ R_2]$

$C' = C_1' \cup C'$

$\mu_{C'}(z,t) = \max\min\{[\mu_{A'}(x) \wedge \mu_{B'}(y)], \mu_R(x,y,z,t)\}$

$= \vee_{x,y,z}\{[\mu_{A'}(x) \wedge \mu_{B'}(y)] \wedge [\mu_{R_1}(x,y,z,t) \vee \mu_{R_2}(x,y,z,t)]\}$

$\mu_{C'}(z,t) = \vee_{x,y,z}\{[\{[(\mu_{A'}(x) \wedge \mu_{B'}(y)) \wedge \mu_{R_1}(x,y,z,t)]$ V $[(\{[(\mu_{A'}(x) \wedge \mu_{B'}(y)) \wedge \mu_{R_2}(x,y,z,t)]\}$

$\mu_{C'}(z,t) = \mu_{C_1'}(z,t) \vee \mu_{C_2'}(z,t)$

$\mu_{C'}(z) \wedge \mu_{T'}(t) = [\mu_{C_1'}(z) \wedge \mu_{T_1'}(t)]$ V $[\mu_{C_2'}(z) \wedge \mu_{T_2'}(t)]$.(8)

To establish the above relationship, membership functions for outputs $\mu_{C'}(z)$, $\mu_{C_1'}(z)$ and $\mu_{C_2'}(z)$ are required along with the output states time membership functions $\mu_{T'}(t)$, $\mu_{T_1'}(t)$ and $\mu_{T_2'}(t)$.

A. Representation of Compositional Rules of Inference with time control.

If B is a fuzzy set of output y and F is a fuzzy relation on Y ×t then T the fuzzy set of time can be determined. In order to find it,

We construct cylindrical extension c(B) with base B by expanding the domain of B from Y to Y ×t.

Let $\mu c(B)$, μ_B, μ_F and μ_T be the MFs of c(B), B, F and T respectively. as

$\mu_C(B)(y,t) = \mu_B(y)$

$\mu_C(B) \cap F(y,t) = \min[\mu_{C(B)}(y,t), \mu_F(y,t)]$ (9)

$= \min[\mu_B(y), \mu_F(y,t)]$

by projecting C(B) ∩F onto the t-axis , we get

$\mu_T(t) = \max_y \min[\mu_B(y), \mu_F(y,t)]$

$\mu_T(t) = \vee_y[\mu_B(y) \wedge \mu_F(y,t)]$ (10)

$T = B \circ F = B \circ (B \rightarrow T)$ (11)

This relation formalizes an inference of fuzzy reasoning for fuzzy control time and fuzzy output variable and infers the truth of proposition T from the truth of B and the implication $B \rightarrow T$.

In order to regulate our control philosophy, we suppose t =f(y) where t is the time of control. We assume that T is a fuzzy set of t and F is a fuzzy relation on Y×t.

The cylindrical extension C(B) of base B expands the domain of B from Y to Y× t to get C(B) with membership function μ_C (B), fuzzy relation F(y,t) on y and t with membership function $\mu_F(y,t)$ and the intersection of C(B) and F in the form of membership grade $\mu_C(B) \cap F(y,t)$.

The Projection of C(B)∩F gives the membership function $\mu_T(t)$ and infers t as a fuzzy set T for specific output value.

Similarly we can represent the compositional rule of inference between input variable x and the output variable y. The truth of a proposition B from the truth of A and the implication $A \rightarrow B$ is given as:

$\mu_B(y) = \max_x \min[\mu_A(x), \mu_F(x,y)]$

$\mu_B(y) = \vee_x[\mu_A(x) \wedge \mu_F(x,y)]$

$B = A \circ F = A \circ (A \rightarrow B)$ (12)

Where $\mu_B(y)$, $\mu_A(x)$ and $\mu_F(x,y)$ are M.F's of B,A and F respectively.[2] (7)

IV. FUZZY LOGIC CONTROLLER AND FUZZY DISCRETE EVENT CONTROL SYSTEM.

A. Fuzzy Logic Controller

A fuzzy logic system consists of fuzzifier, inference engine, aggregator and defuzzifier as shown in Figure 1.

Fuzzifier is used for the fuzzification of input crisp values. The input values are converted into linguistic variables. During this process the membership functions defined on the input values are applied to their actual values [18],[19]. This determines the degree of truth for each rule premise, let X = A , $X = \int \mu_A(x)\ x$. The inference engine computes the truth value for the premise of each rule and applies to the conclusion part of each rule.

Let X = A then Y = B (Premise of each rule)
Y is B (Conclusion).

In aggregator or composite part, all of the fuzzy sets assigned to each output variable are combined together to form a single fuzzy set for each output variable.

The defuzzifier is used for defuzzification. This part converts the fuzzy output set to a non fuzzy crisp number[20],[21].The fuzzy controller is designed to perform fuzzy logic operations on fuzzy set (set of linguistic variables) representing linguistic variables in a qualitative set of control rules by using knowledge base, fuzzy expert system[22],[23].

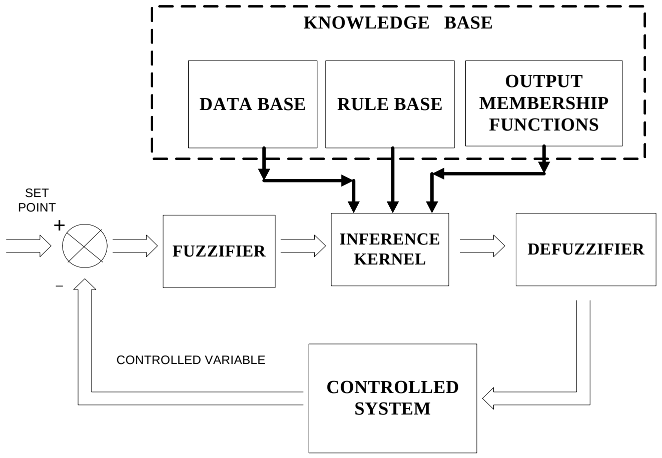

Figure 1: Fuzzy logic controller block diagram

B. Fuzzy Discrete Event Control System.

Fuzzy logic time control system (FLTCS) along with a discrete event system (DES)[24],[25] is proposed to be a fuzzy discrete event control system (FDECS)[26],[27].

Fuzzy logic time control system needs, fuzzifier, inference kernel connected with knowledge base inclusing data base, rule base and output membership functiobs (for output variable and output time control) information. In this system two defuzzifiers, one for outpart variable and another for output time control are used.

Time control pulser converts the time crisp value into a pulse of specific time duration.

In analog to digital converter (ADC) pulse strobe unit, ADC converts the output crisp value into binary code and pulse strobe part allows the code to pass for the specific pulse duration. This binary code is used to activate the discrete event control system to generate specific event for a certain time. In this way combination of fuzzy logic time control system and discrete event system will form a fuzzy discrete event control system[28],[6].

V.MODELLING AND IMPLEMENTATION, FUZZY TIME CONTROL SYSTEM WITH DEVS.

Figure 3(b) shows a hierarchical modular composition of components and coupling for a fuzzy logic time control DEV system [26] The system is composed of an experimental frame system(EFS) and process control system(PCS).

Experimental frame system (EFS) is a fuzzy time control system. Experimental control system (EFS) is decomposed into two atomic models, Generator (G) and time control (TC).

The G model generates request in the form of crisp value of output variable and TC model generates the crisp time value of the output fuzzy variable.

Binary decoded value of crisp output variable provides the code to the various event control blocks of the DEV system.

DEV system is a process control system (PCS). improve the accuracy of the system and the sensitivity of the system can also be controlled.

Output time control membership functions can be determined according to the fuzzy rules and will enable the output only for the determined time.

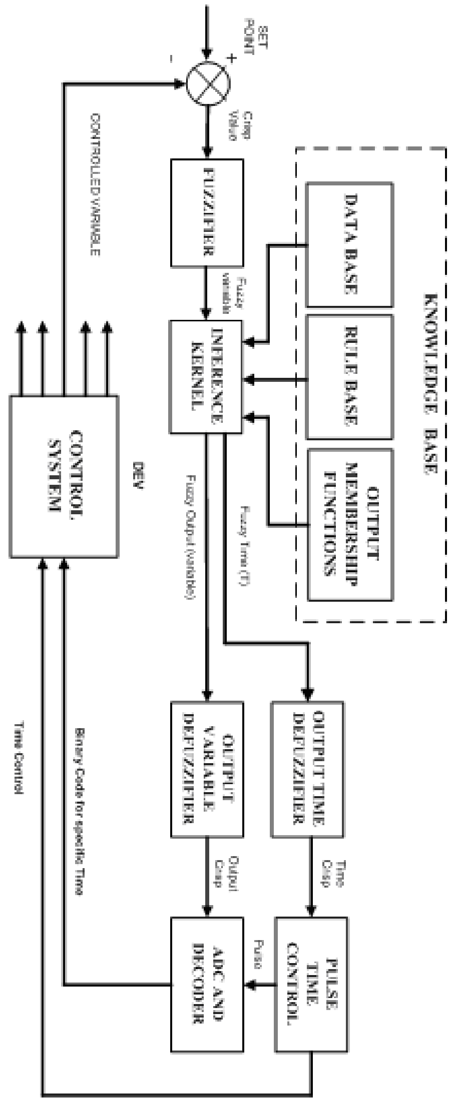

Figure 2: Fuzzy discrete event controller system (FDECS) block diagram.

This extra hardware requirement can be avoided by using extra software programming technique in rule base system of the fuzzy controller.

Fuzzy logic system can also be used in a different way, the crisp output values from the defuzzifier can be compared with a certain level and converted into binary values logic 1 or logic 0 for a specified control time and used to control the values or components for input parameters to active ON or OFF for the specific fuzzy rule.

This technique will enhance the control ability of the system and event based fuzzy control system can be efficiently implemented with this enhanced functionality.

This time control model can be implemented on the other fuzzy models: Mamdani's fuzzy model, Sugeno fuzzy model and Tsukamoto fuzzy model.

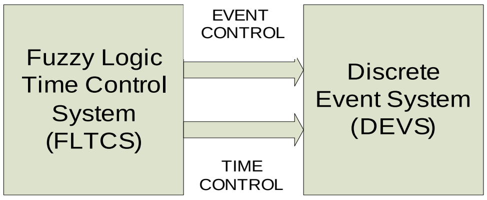

Figure 3(a) Two modules of FDECS.

PCS model has three atomic models; Event Control, which manages events and accepts FLC requests for an event; Process Control, which manages a process and accepts the event specified by the fuzzy logic control FLC as well the requests from an atomic model system control; and System Control, which manages the whole system and schedules the requests of event controls[26].System control and process control are activated for the prescribed time, generated by the fuzzy logic time control system (FLTCS). The process control also provides the adjustment value to the input of fuzzy control system.

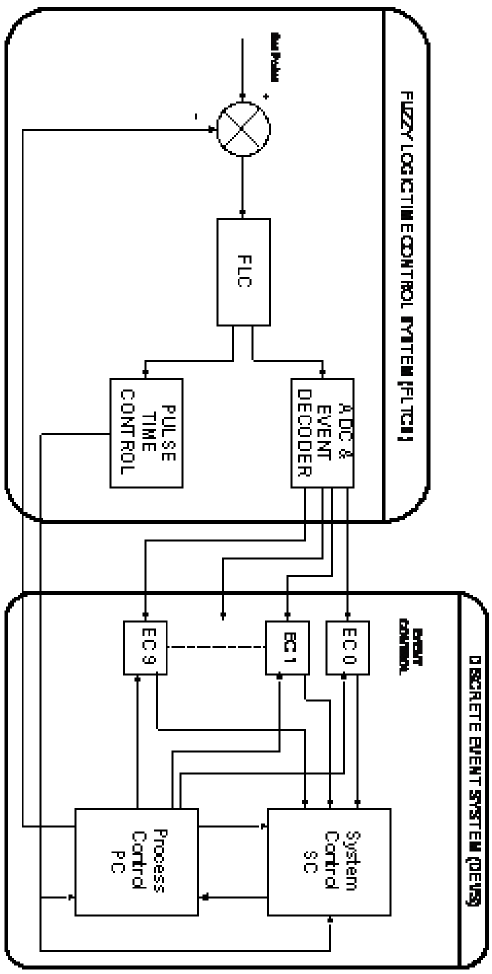

Figure 3(b): Hierarchical modular composition of components and coupling for a fuzzy logic time control DEV system.

VI.CONCLUSION.

We can improve the efficiency of the system by the time control of the output values. Fuzzy logic time control will Time defuzzifier, timing control sequencer, ADC and decoder are needed for the implementation of this technique. This new technique is deterministic and reduces the complexity of the existing fuzzy DEV system. This makes possible to combine fuzzy logic systems with the DEV systems as well as with the discrete time system DTS with the minor hardware burden. This system can also work as a fuzzy discrete time control system with minor changes in system control, time control and event selection techniques. This new approach will reduce the complexity of traditional modeling and its implementation. These advantages of the new system will make the system popular in control system industry.

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