Fuzzy-Neuro Controller for Control of Air-Conditioning System

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ABSTRACT

A practical application of a fuzzy-neuro controller is described for an air-conditioning system. Air-handing units are being widely used for improving the performance of central air-conditioning systems. The fuzzy-neuro control system has two controlled variables, temperature and humidity,and three control elements, cooling, heating, and humidification. In order to achieve high efficiency and economical control, especially in large offices and industrial buildings, two controllable parameters, temperature and humidity, must be adequately controlled by the three final controlling elements. In this paper a fuzzy-neuro control system is described for controlling air-conditioning systems efficiently and economically. Simulation results confirmed that the fuzzy neuro control system is effective for this multivariable system.

I. Introduction

Fuzzy-neuro control systems are presently being used in a number of different appliances, including washing machines and vaccum cleaners. The economical control of air quality in residential, large office and industrial buildings is challenging since there can be significant changes in the environmental and atmospheric conditions. Air handing units are, therefore, widely used in the control of air conditioning systems. In this paper, a novel fuzzy-neuro control system is described with the capability of controlling temperature and humidity by appropriate control of three control elements: cooling, heating and humidifying valves. First, the general theory of fuzzy-neuro control system is explained. Next the design of a multivariable fuzzy-neuro control system of the air-conditioning system is given. In order to achieve high efficiency and economical control, two parameters, temperature and humidity must be adequately controlled through the control variables. A fuzzy-neuro control system for the air-conditioning system that is presented in this paper provides smooth control with efficient operations. A general fuzzy-neuro control system is developed in Section II. Section III of this paper contains a block diagram of the fuzzy logic neuron and a description of the air-conditioning system. Section IV deals with the output signals of the fuzzy logic neuron and defuzzification. Simulation results and conclusions are presented in Sections V and VI, respectively.

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II. Fuzzy-Neuro Control System

In order to develop the fuzzy-neuro control system, some basic mathematical operations pertinent to such a system are first presented. A single-input, single-output open-loop fuzzy logic neuron is illustrated in Fig. 1.

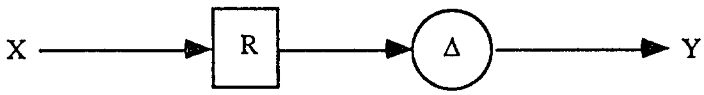


Fig. 1. Single-input single-output open-loop fuzzy logic neuron.

where Ⓐ is the neural operations between input X and output Y, and R is the relation between input X and output Y.

Suppose that an operator provides a hypothetical verbal description of this process in the form of fuzzy implications connected by the conjunction ALSO.

IF $X_{(1)}$ THEN $Y_{(1)}$
ALSO
IF $X_{(2)}$ THEN $Y_{(2)}$
ALSO
⋮
IF $X_{(i)}$ THEN $Y_{(i)}$
⋮
ALSO
IF $X_{(n)}$ THEN $Y_{(n)}$

where $X_{(i)}$ is the fuzzy value of the i_{th} process input and $Y_{(i)}$ is the corresponding fuzzy value of the process output, $i = 1, 2, ..., n$.

To calculate the output Y, given X and the fuzzy relation R, the compositional rule of inference is used [5], [6], [7]

$$Y = X \circ R$$

where $\circ$ is the max-min composition of the fuzzy relations.

A multivariable fuzzy logic neuron is shown in Fig. 2.

This system has four inputs and two outputs. Therefore, a linguistic description of the process is as follows:

Suppose that the input and output signals are of a fuzzy nature, and let the neuron be trained by the following set of fuzzy rules:

{IF $X^1_{(i)}$ and $X^2_{(i)}$ and $X^3_{(i)}$ and $X^4_{(i)}$ THEN $Y^1_{(i)}$ and $Y^2_{(i)}$, ALSO}

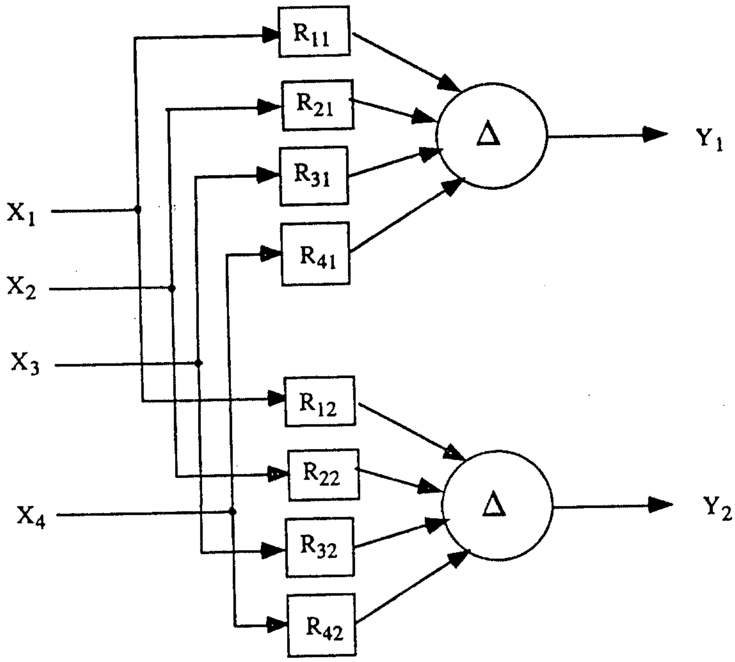


Fig. 2. Multi-input multi-output fuzzy logic neuron.

$i = 1, 2, 3, \ldots, I.$

where $X^1_{(i)}$, $X^2_{(i)}$, $X^3_{(i)}$, $X^4_{(i)}$ are the fuzzy values of the input variables, X^1, X^2, X^3, X^4 defined in the universe of discourses X_1, X_2, X_3, X_4 respectively; and $Y^1_{(i)}$, $Y^2_{(i)}$ are the fuzzy values of the output variable Y^1, Y^2 defined in the universe of discourse Y_1, Y_2; $i = 1, 2, 3, \ldots$ I is the number of fuzzy rules, and ALSO is the linguistic connector.

To obtain the present outputs, Y_1, Y_2, given the current inputs, X_1, X_2, X_3, X_4, the following compositional rule of inference[8] is used

$$Y = X_1 \circ X_2 \circ X_3 \circ X_4 \circ R$$

The result of the composition is a compound fuzzy set Y in the universe $Y_1 \times Y_2$, [8], [9], where $\times$ is the Cartesian product.

Ⅲ. Fuzzy-Neuro Model of an Air-Conditioning System

An inference structure of a fuzzy-neuro control system in an air-conditioning system is shown in Fig. 3, and the basic structure scheme of an air-conditioning system is shown in Fig. 4 The input and output variables of the fuzzy-neuro control system are shown in Fig. 4.

Where the input variables are: X_1: Temperature condition

X_2: Humidity condition

X_3: Cooling valve condition
X_4: Heating valve condition
X_5: Humidifying valve condition
and the output variables are: Y_1: Cooling valve operation
Y_2: Heating valve operation
Y_3: Humidifying valve operation

A block diagram of multivariable fuzzy-neuro control system used in an air-conditioning system is shown in Fig. 5.

The control algorithm is described using

"IF ... THEN ..." fuzzy-neuro control rules.

1) IF X_1 = SM AND X_2 = SM AND X_3 = M AND X_4 = S AND X_5 = SM
THEN Y_1 = NZ AND Y_2 = ZP AND Y_3 = Z

ALSO

2) IF X_1 = SM AND X_2 = M AND X_3 = SM AND X_4 = SM AND X_5 = M
THEN Y_1 = Z AND Y_2 = Z AND Y_3 = NZ

ALSO

3) IF X_1 = ZS AND X_2 = M AND X_3 = MB AND X_4 = Z AND X_5 = M
THEN Y_1 = N AND Y_2 = ZP AND Y_3 = NZ

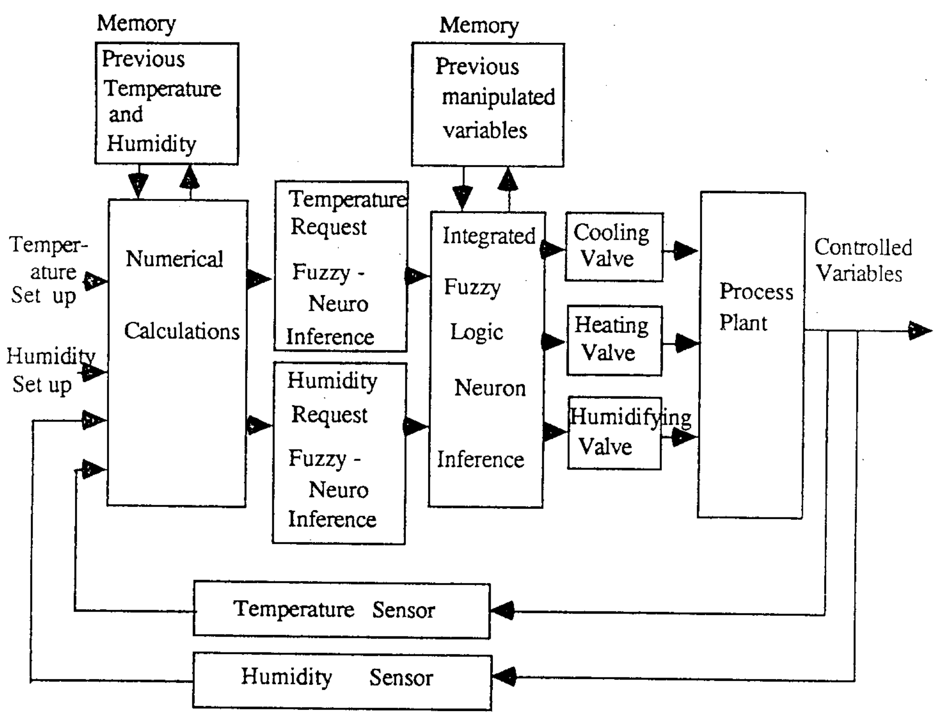


Fig. 3. A general inference structure of a fuzzy-neuro control system in an air-conditioning system.

ALSO

4) IF $X_1 = B$ AND $X_2 = ZS$ AND $X_3 = Z$ AND $X_4 = B$ AND $X_5 = ZS$
THEN $Y_1 = P$ AND $Y_2 = N$ AND $Y_3 = ZP$

ALSO

5) IF $X_1 = ZS$ AND $X_2 = B$ AND $X_3 = MB$ AND $X_4 = Z$ AND $X_5 = B$
THEN $Y_1 = NZ$ AND $Y_2 = ZP$ AND $Y_3 = N$

ALSO

⋮

The membership functions of the input variables and output variables are shown in Figs. 6 and 7, respectively.

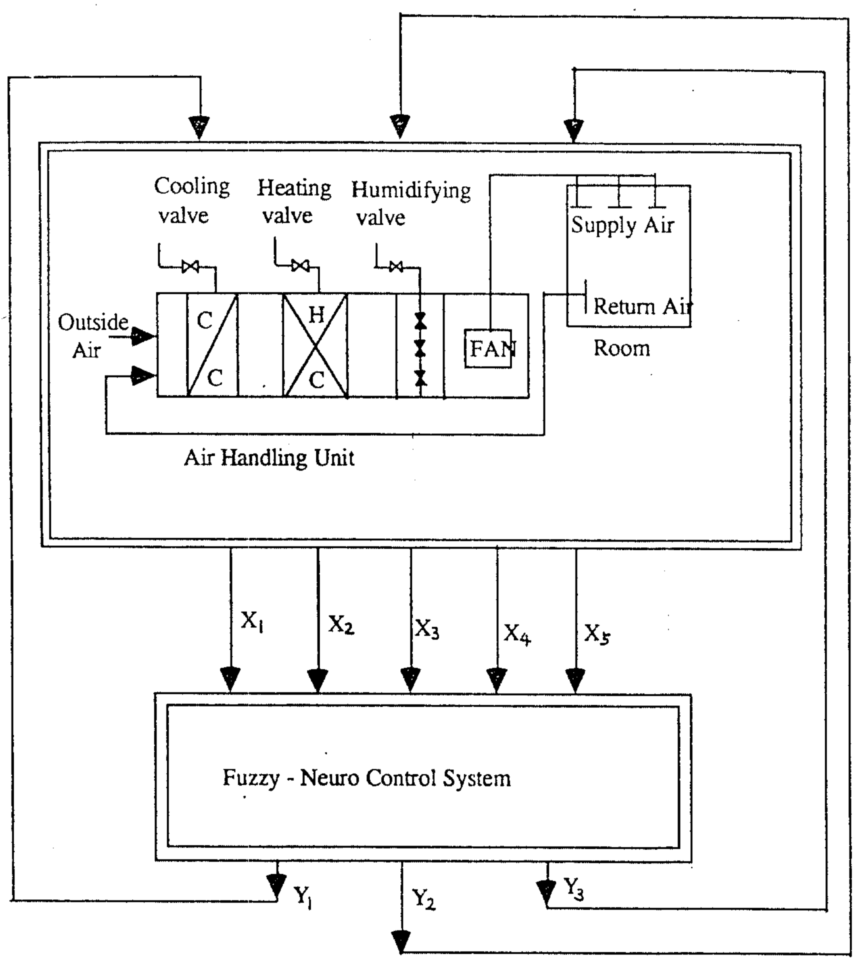


Fig. 4. The basic structure scheme of an air-conditioning system.

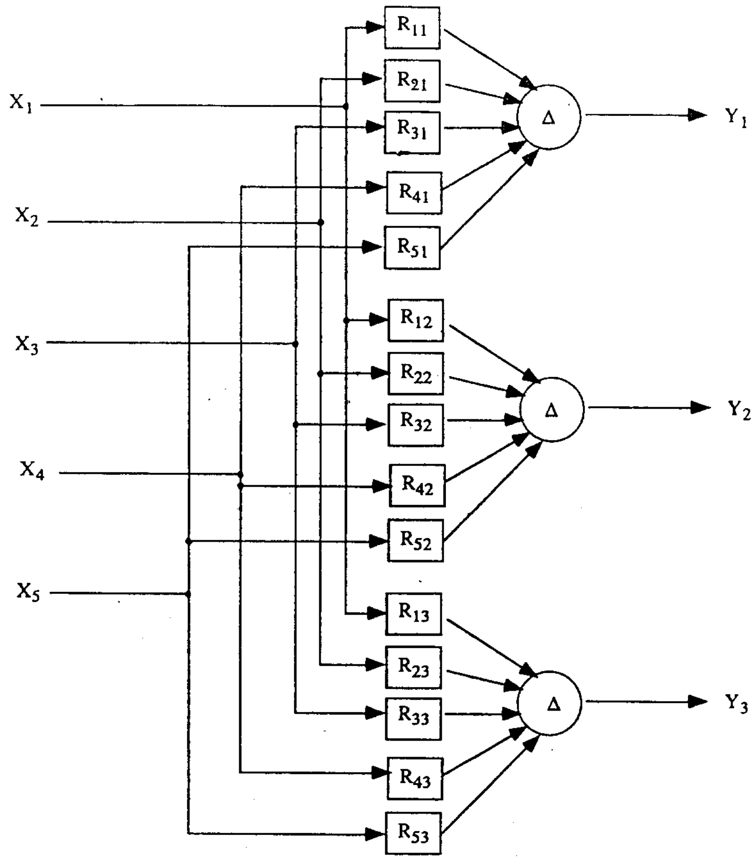
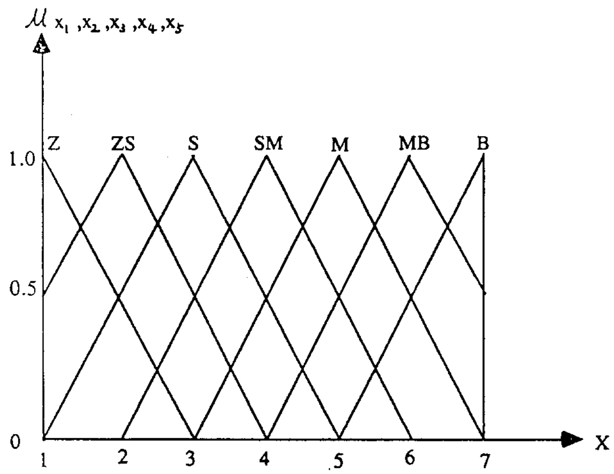


Fig. 5. Block diagram of a fuzzy-neuro control system in an air-conditioning system.



Z = Zero, ZS = between Zero and Small, S = Small,
SM = between Small and Medium, M = Medium,
MB = between Medium and Big, B = Big.

Fig. 6. Membership function of the input variables X_1, X_2, X_3, X_4 and X_5.

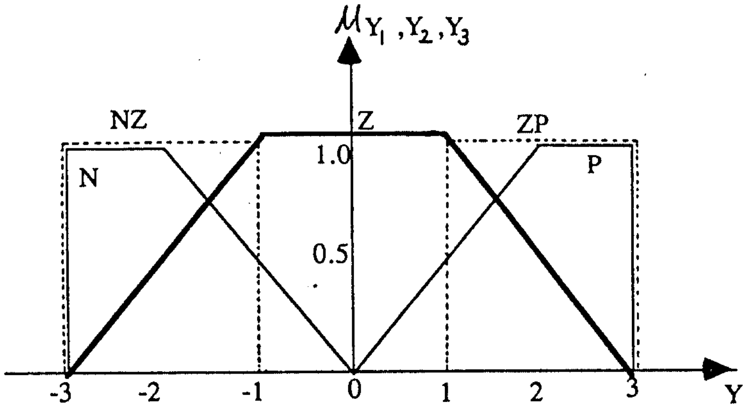


Fig. 7. Membership function of the output variables Y_1, Y_2 and Y_3.

Ⅳ. Output Signal of Fuzzy Logic Neuron and Defuzzification

The multivariable fuzzy logic neuron in an air-conditioning system can now be described by the following fuzzy equation:

$$Y_1 = \{X_1 \circ R_{11}\} \Delta \{X_2 \circ R_{21}\} \Delta \{X_3 \circ R_{31}\} \Delta \{X_4 \circ R_{41}\} \Delta \{X_5 \circ R_{51}\}$$
$$Y_2 = \{X_1 \circ R_{12}\} \Delta \{X_2 \circ R_{22}\} \Delta \{X_3 \circ R_{32}\} \Delta \{X_4 \circ R_{42}\} \Delta \{X_5 \circ R_{52}\}$$
$$Y_3 = \{X_1 \circ R_{13}\} \Delta \{X_2 \circ R_{23}\} \Delta \{X_3 \circ R_{33}\} \Delta \{X_4 \circ R_{43}\} \Delta \{X_5 \circ R_{53}\}$$

where X_1, X_2, X_3, X_4 and X_5 are the current inputs, and Y_1, Y_2 and Y_3 are the present outputs. It is more convenient to express the perceptron process in terms of the vector-matrix notation [2], [3], [4]. The output signals of the neuron can be expressed as

$$\begin{pmatrix} Y_1 \\ Y_2 \\ Y_3 \end{pmatrix}^T = [X_1 \quad X_2 \quad X_3 \quad X_4 \quad X_5] * \begin{pmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \\ R_{41} & R_{42} & R_{43} \\ R_{51} & R_{52} & R_{53} \end{pmatrix}$$

where * means the($\circ$, Δ) composition, T means the transposition.

The fuzzy relations R_{11}, R_{21} ... R_{53} are defined by the following mappings:

$R_{11} : X_1 \times Y_1 \rightarrow [0, 1]$
$R_{21} : X_2 \times Y_1 \rightarrow [0, 1]$
$R_{31} : X_3 \times Y_1 \rightarrow [0, 1]$
$R_{41} : X_4 \times Y_1 \rightarrow [0, 1]$
$R_{51} : X_5 \times Y_1 \rightarrow [0, 1]$

$R_{12} : X_1 \times Y_2 \rightarrow [0, 1]$

$R_{22}: X_2 \times Y_2 \rightarrow [0, 1]$
$R_{33}: X_3 \times Y_2 \rightarrow [0, 1]$
$R_{43}: X_4 \times Y_2 \rightarrow [0, 1]$
$R_{53}: X_5 \times Y_2 \rightarrow [0, 1]$

$R_{13}: X_1 \times Y_3 \rightarrow [0, 1]$
$R_{23}: X_2 \times Y_3 \rightarrow [0, 1]$
$R_{33}: X_3 \times Y_3 \rightarrow [0, 1]$
$R_{43}: X_4 \times Y_3 \rightarrow [0, 1]$
$R_{53}: X_5 \times Y_3 \rightarrow [0, 1]$

where $\times$ is the Cartesian product, and $\circ$ is the max-min composition, and Δ is the contribution operator.

Specifically, the fuzzy relations and fuzzy operators can be defined as follows:

$$R_{11}(X_1, Y_1) = \bigwedge_{i=1}^{I} \begin{cases} 1, & X^1_{(i)} \leq Y^1_{(i)} \\ X^1_{(i)}, & X^1_{(i)} > Y^1_{(i)} \end{cases}$$

$$R_{21}(X_2, Y_1) = \bigwedge_{i=1}^{I} \begin{cases} 1, & X^2_{(i)} \leq Y^1_{(i)} \\ X^2_{(i)}, & X^2_{(i)} > Y^1_{(i)} \end{cases}$$

$$R_{31}(X_3, Y_1) = \bigwedge_{i=1}^{I} \begin{cases} 1, & X^3_{(i)} \leq Y^1_{(i)} \\ X^3_{(i)}, & X^3_{(i)} > Y^1_{(i)} \end{cases}$$

⋮

⋮

$$R_{53}(X_5, Y_3) = \bigwedge_{i=1}^{I} \begin{cases} 1, & X^5_{(i)} \leq Y^3_{(i)} \\ X^5_{(i)}, & X^5_{(i)} > Y^3_{(i)} \end{cases}$$

where Λ is the min operator.

The output of the fuzzy-neuro controller is a fuzzy set of control signals. A practical process for control requires a nonfuzzy value of control. Therefore, the system needs a "defuzzification stage", which can be expressed as follows:

U_0 = defuzzifier(U), U : fuzziness value of inference, U_0: defuzzification value of control.

Typical methods of defuzzification are the maximum criterion method, the mean of maximum method and the center of area method. In this paper the mean of maximum method is used.

V. Results of Simulation

A fuzzy-neuro program performing fuzzy-neuro control in an air-conditioning system was programed. The results of these simulations showed that the multivariable fuzzy-neuro control system operated well enough in the air-conditioning system.

Example 1.

In the first case, the following input signals were used:

$X_1 = SM, X_2 = M, X_3 = SM, X_4 = SM, X_5 = M.$

The output signals were

$Y_1 = [0.5, 0.5, 1.0, 1.0, 1.0, 0.5, 0.5] \cong Z$

$Y_2 = [0.5, 0.5, 1.0, 1.0, 1.0, 0.5, 0.5] \cong Z$

$Y_3 = [1.0, 1.0, 1.0, 0.5, 0.5, 0.5, 0.5] \cong NZ$

and the defuzzification values were

$Y_1 = 0.0$

$Y_2 = 0.0$

$Y_3 = -2.0$

This is explained as follows:

IF the temperature condition is between Small and Medium, the humidity condition is Medium, the cooling valve condition is between Small and Medium, the heating valve condition is between Small and Medium and the humidifying valve condition is medium, THEN the cooling valve operation is not changed, the heating valve operation is not changed and the humidifying valve operation is closed by the control value of -2.0 level.

Example 2.

In the second case the following input signals were used

$X_1 = B, X_2 = ZS, X_3 = Z, X_4 = B, X_5 = ZS.$

The output signals were

$Y_1 = [0.0, 0.0, 0.0, 0.0, 0.5, 1.0, 1.0] = P$

$Y_2 = [1.0, 1.0, 0.5, 0.5, 0.5, 0.5, 0.0] \cong N$

$Y_3 = [0.0, 0.0, 0.0, 0.0, 1.0, 1.0, 1.0] = ZP$

and the defuzzification values were

$Y_1 = 2.5$

$Y_2 = -2.5$

$Y_3 = 2.0$

This is explained as follows:

IF the temperature condition is Big, the humidity condition is between Zero and Small, the cooling valve condition is Zero, the heating valve condition is Big and the humidifying valve condition is between Zero and Small, THEN the cooling valve operation is opened by the control value of 2.5 level, the heating valve operation is closed by the control value of -2.5 level and the humidifying valve operation is opened by the control value of 2.0 level.

Ⅵ. Conclusions

A fuzzy logic neuron has been outlined in this paper in terms of the temporal vector-matrix fuzzy equations. The method presented in this paper allows for the analysis and synthesis of a multivariable compound fuzzy-neuro system.

In this paper a fuzzy-neuro control system has also been presented for the efficient and economical control of an air-conditioning system. From the results of the simulations, the fuzzy-neuro control system was found to be effective for this multivariable control system.

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