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Modeling and simulation controlling system of HVAC using fuzzy and predictive (radial basis function, RBF) controllers

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ABSTRACT

Heating, ventilating and air conditioning (HVAC) systems are used in buildings, industry and agriculture to provide thermal and humidity comfort. Modeling of HVAC system can help to design precise controlling systems. In this study, a HVAC system had been modeled using MATLAB simulation software that had been developed using a fuzzy controlling system and radial basis function (RBF) model of artificial neural network (ANN) as a predictive control system. Results of the modeled systems were extracted and compared with actual system. In order to compare results of the modeled and actual systems, comparing parameters, such as mean absolute error (MAE), root mean square error (RMSE), mean absolute percentage/relative error (MAPE) and coefficient of Pearson correlation (r) were applied. The results indicated that, the modeled systems was accurately controlling the system and the difference between real and modeled system was also close. In the results as a whole, the predictive controller (RBF network) has the best performance compared to fuzzy model.

1. Introduction

Heating, ventilating and air conditioning (HVAC) systems are widely used in industrial and agricultural production units, such as greenhouses and poultry farms. Components of a typical HVAC system include indoor and outdoor air loops, condenser, chilled water and refrigerant loops [1]. Many control methods have been developed in order to control a HVAC system. In many HVAC systems, the on/off and proportional integral derivative (PID) controllers are used, because they are unique programmable controllers. Developing the data storage, computing, communication systems, adopting and implementing an appropriate control system, help to predominate the problems arising from HVAC control system [2]. In spite of the classic control systems, intelligent control systems can do complex tasks without the need to know the mathematical model of the system. In recent years, intelligent and soft computing methods were used in all fields of science. Neuro-fuzzy controller is one of these intelligent methods which have been used in the synthesis with PID by Soyguder and Alli to control a HVAC system. In this system, PID controller has been used to control damper gap rates and neuro-fuzzy inference systems were used to predict damper gap rates of the HVAC system [3,4]. Chen and Treado introduced a simulation platform with customized Simulink block library on MATLAB software based on dynamic HVAC component model. As an initiating effort, the current simulation platform is composed of basic modular HVAC components, including conduit, damper, valve, fan, pump, flow merge, flow split, heating coil, cooling coil, and zone [5]. Orosa proposed a new model of thermal comfort based on P.O. Fanger PMV index according to the Kansas University Institute and modified it to a specific indoor ambience with a logger of thermal comfort. The results indicated that this way nominates enough accuracy and suggests temperatures, such as a standard HVAC system [6]. Predictive control is implemented in industrial applications to advance control strategies [7]. Neural network is a predicting method that has learning ability to approximate any nonlinear function. The neural networks (NNs) are suitable to control nonlinear dynamical systems with unknown control coefficient matrixes [8]. Radial basis function (RBF) is one of the various types of artificial neural networks (ANNs) that has become popular in engineering applications, because it is able to predict complex nonlinear mappings directly from the input-output and it has a simple topological structure [9]. The main objective of this work was to develop a simulation model of a HVAC system using fuzzy controller and a prediction model by RBF network of ANN and compare two models. The main advantage of this study compared to other modeling and simulation studies, is to compare ANN and a designed fuzzy controller that was studied on a real

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Nomenclature

A	Heat transfer area (m^2)
C_p	Specific heat (kj/kg. k)
D	Diameter (m)
h	Heat transfer coefficient ($w/c^o. m^2$)
k	Thermal conductivity (w/m. k)
L	Length (m)
M	Mass (kg)
m	Mass flow (Kg/s)
Nu	Nusselt number
Pr	Prandtl number
q	Heat transfer (w)
Re	Reynolds number
RH	Relative Humidity (%)
Sprayer	Rate of water spraying (m^3/s)
T	Temperature (°C)
U	Overall heat transfer coefficient (Kw/m^2c^o)
v	Volume of area (m^3)
V	Ventilation rate (m^3/s)

Subscripts

a	Air
amb	Ambient
ex	External
in	Internal, Indoor
max	Maximum
out	Outdoor
Sa	Supply air
r	Roof
Sa	Supplied air
W_1	East and West walls
W_2	South and North walls

and actual condition. The fuzzy system had been generated using simple equations and the actual used rules. Due to the nature of the system that is derived from the real system, the system can be operated using simple equipment and measures in real condition. This models and methods can help to optimize the use of the system to achieve the best performance. This study includes 4 stages, the first stage develops simulation model of a HVAC system based on heat transfer equations, the second stage designs a fuzzy controller to control simulated model, the third stage develops RBF model of ANN based on the achieved data from operation of actuators and output of the system and the last stage compares the developed models performance and real system.

2. Materials and methods

2.1. Measurement

Experiments were carried out on a HVAC system in one of the mushroom growing farms of Ardabil province of Iran. Three PT-100 sensors and one HIH-4000 sensor were used to measure the output temperature and relative humidity of the studied system, respectively. All data were recorded using DAQ Master, the interface software of temperature measuring device, and a data logger for recording relative humidity data. The value of temperature was calculated to be the average of three local measurements. In order to record the required data, the strategy of Fig. 1 was used:

As shown in Fig. 1, the operating range of each actuator was divided into 4 functional areas (25%, 50%, 75% and 100% of maximum operating range). Related outputs were recorded by combining each of these functional areas to actuators. Any data recorded with 2 repeats and the average of them was calculated. In order to define fuzzy rules, data were collected in two stages. First, the position of actuators were changed, then after stabilizing the situation (temperature and relative humidity), data were recorded. The second phase was to achieve the rate of variable changes, so in this stage the time of changes were also measured. All of these operations were performed in the frequency of 7 days with 3 repetition each day. The ambient temperature and relative humidity were also recorded during each record.

2.2. HVAC modeling

In heating and air-conditioning systems of heat exchanger, liquid or gas flow is widely used. Heat transfer in a heat exchanger,

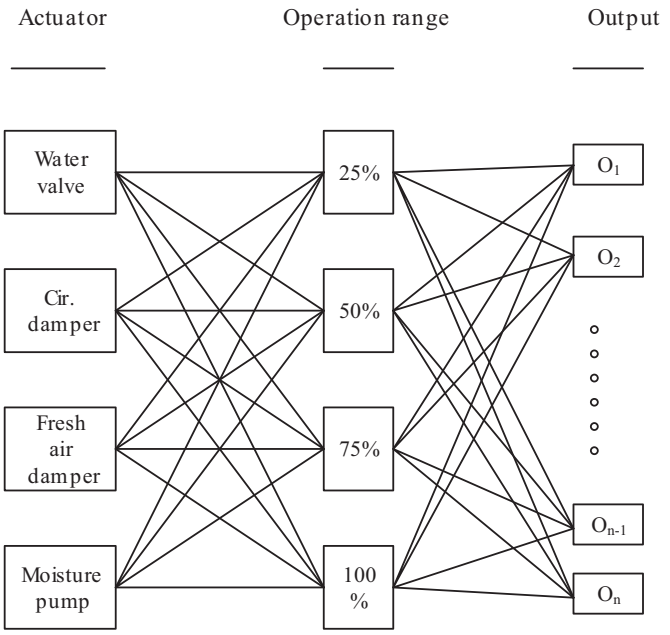

Fig. 1. Controlling strategy of data recording.

which usually involves convection in each fluid and conduction through the wall separating the two fluids. It is convenient to work with an overall heat transfer coefficient (U) when analyzing heat exchangers that accounts for the contribution of all these effects on heat transfer. Heat transfer between two fluids is a process that occurs on HVAC systems [10]. Due to the extension of available relationships on different resources for all kinds of flows and heat transfer systems, the characteristics of the real system need to be adapted to model HVAC system by some relationships. By doing this, the required relationships should be reached. The goal HVAC system had some operating characteristics. To simulate this system and extract the required equations and relationships, the following conditions should be considered:

- The goal HVAC system has one loop that is for hot water.
- The study is done in cold climate region, so the fresh air damper was adequate to cool the system.
- The supplied air by fan has the fixed rate.
- The air flow on water loop is cross flow.