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Studies on sensor fault validation in VAV air-conditioning system using Artificial Neural Network

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ABSTRACT *: A dynamic ANN model to study sensor fault validation scheme in a variable-air-volume-air-conditioning system has been developed. A single network is used for predicting fault in one sensor only whether it is ramp or step or random type fault and system performance is studied after fault is detected. The ANN model used here is a feed-forward multilayer perceptron using Backpropagation Algorithm. The simulation result obtained is found to be in close conformity with the normal values.*
Keywords – Artificial Neural Network, Backpropagation Algorithm, Feed-forward Multilayer Perceptron, Variable-air-volume-air-conditioning System.

I. INTRODUCTION

A Variable-Air-Volume-Air-Conditioning (VAVAC) system varies the volume of constant temperature air that is supplied to meet the challenging load condition of the space. The VAVAC systems are becoming the choice of the air conditioning for office environment in the South-Asia owing to their efficiency and capability for individual zone temperature control. Studies on VAVAC system have been a subject of interest owing to increase in down time due to fault and wastage of energy to a very large extent [1]. Research is on for development of economic use of VAVAC system [2] and fault identification, validation, isolation and fault tolerant control in VAVAC system [3-13]. In a VAVAC system, the flow rate of supply air changes with the thermal load in the condition space. The basic principle of Variable-Air-Volume (VAV) system is to control both the volume and temperature of air being introduced to a space for heating, ventilation and air-conditioning. The VAVAC system delivers the primary air at a constant temperature and varies therefore to maintain the require space temperature at all load conditions. The flow rate control is accomplished through differences and control devices such as VAV boxes incorporating controlled motorized dampers employing the space conditions (temperature and humidity) as set points. The system is capable of providing optimal operating point minimizing energy consumption by the system, while at the same time meeting the requirements on user comfort.

A given temperature set points of the system is achieved through more than a single setting of parameter that controls the system response. To ensure reliable and trouble free system operation, conditions measurement and monitoring of process variables such as water flow rates, air pressure, damper position, temperature of air and water, flow speed etc are required. A sensor failure at any instant results in system to be halted in order that it be isolated and replaced leading to considerable discomfort to the occupants. Thus fault detection and isolation using process monitoring software is necessary and a control algorithm that can tolerate this fault is of urgency as it can substantially reduce the down time. It is here that Artificial Neural Network (ANN) comes to play and such fault correction is done applying Backpropagation Algorithm. A subsystem model describing functional relationships between appropriate inputs and outputs is developed and used here for simulation. The system fault tolerance is materialized by training an ANN to estimate the output of each sensor from the remaining normal once. When this estimate is found to substantially deviate from the actual sensor measurement a decision is made regarding which of the sensors has failed. The present scope of work is concerned with only sensor faults and the fault validation scheme so developed takes care of the system performance after the fault is detected. The ANN is trained offline and weights matrix is obtained which is subsequently used for online validation of the single sensor failure of the system in closed loop condition.
Modeling and Design Methodology of Fault Validation Approach

A schematic diagram of a VAVAC system is depicted in Fig. 1.

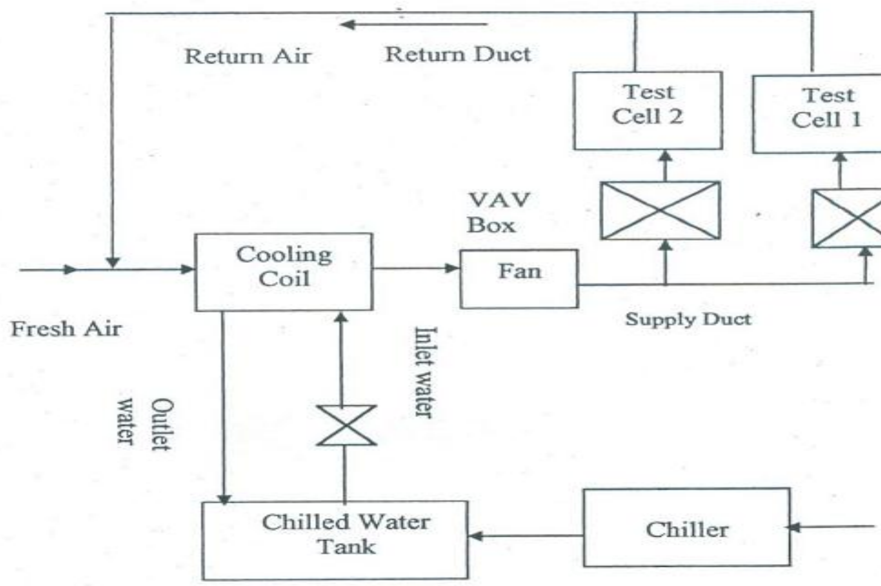

Fig. 1. A two-zone Variable-Air-Volume-Air-Conditioning (VAVAC) system.

The various components of VAVAC system are fan, cooling coil, supply duct, return duct, VAV box, a chiller and a chilled water tank. The opening of zone dampers and fan speed control the supply air flow rate to the test cells. The temperature and humidity of the supply air are controlled by varying the mass flow rate of the chilled water of the cooling coil. The same can also be controlled by varying the chilled water temperature via controlling the chiller input energy. Thus five control inputs can be simultaneously varied in response to zones cooling load variation. The output parameters are supply air flow rate, return air temperature, chilled water temperature, fan speed and static pressure in the duct system. An ANN model is applied here to control the relationships between appropriate input and output parameters.

A VAVAC system, a highly nonlinear dynamic system, experiences more rapidly changing environments and encounter a great verity of unexpected component failures. In this paper the authors have used only one network for fault prediction in one sensor only weather it is ramp or step or random type of fault. The model for fault validation scheme is so developed that it takes care of the system performance after fault detection.

The ANN used here is feed forward multilayer perceptron. The authors have followed two approaches for prediction of fault in one sensor viz., (i). in the first case the present and past values of the sensor are taken and (ii). in the second case the various set point are included. The input pattern containing normal data of the sensor or both sensors and set point are presented to the network for training purpose. The number of input nodes and hidden layers are differently chosen for the above two cases. After proper training the resulting weight set is used in closed loop. This scheme is a gradient descent along the error surface to arrive at the optimal set of weights. In closed loop system provision for selection of the above two cases is present. On selecting Block 1, input to ANN is only sensors while Block 2, selection involves both sensor and set points.

As shown in Fig. 2 there is also provision to provide data to the controller whether directly from sensor or from ANN estimate. Here the simulator output is obtained from the ANN prediction in case of faulty system by both sensors and set points or sensors only. The VAVAC system simulator uses the co-relation among signals to estimate for the faulty data thereby making the system fault tolerant. As the ANN output is used to validate the sensors signals, it also means if any or some sensor signals are erroneous, the ANN will replace those signals with the estimated signals which can be used by the controller for the next time instance. The result obtained after simulation is found to exhibit significant improvement in trajectory following performance based upon the proposed model. The results depict that ANN predictions are excellent and maintains the system value in close agreement to the normal value.

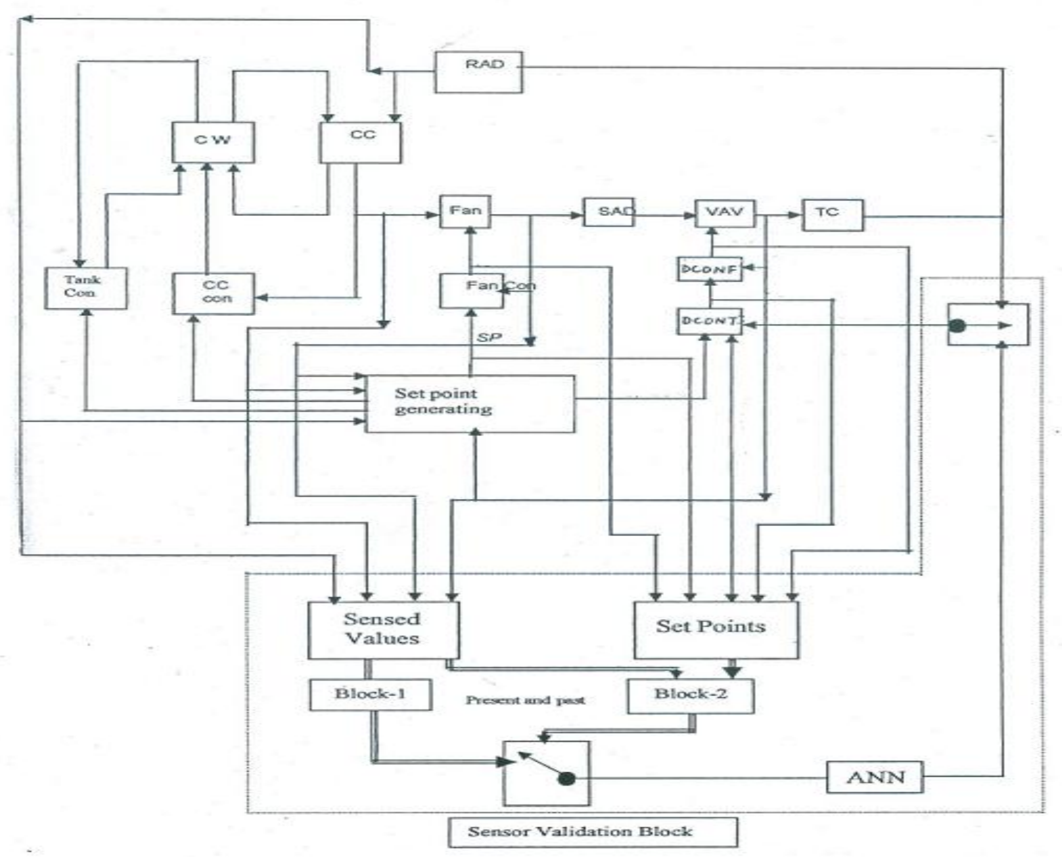

Fig. 2. Sensor Validation Scheme of a VAVAC system.

[CC - Cooling Coil, CW - Chilled Water, DCONF - Damper air flow controller, DCONT - Damper controller for cell temperature, Fan - Main Fan, RAD - Return Air Duct, SP - Static Pressure, SAD - Supply Air Duct, TC - Test Cell, VAV - Variable air volume box.]

II. RESULTS AND DISCUSSIONS

Fig. 3 depicts sensor validation scheme for air flow through damper. Fig. 4 depicts the sensor validation scheme for faulting temperature of test cell while that of Fig. 5 is for validation of temperature of return air. The figures depict a fault in the sensor in the form of a step and the result obtained through ANN is in closed conformity with the normal values. The graph reveals that as soon as fault occur in sensor, the controller takes the decision and ANN starts working in order to restore normal system operation without much degradation in its performance. Thus the simulation results of fault tolerant control obtained are quite encouraging.

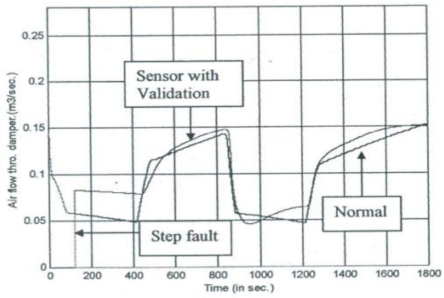

Fig. 3. Sensor Validation Scheme for fault in air flow through damper.

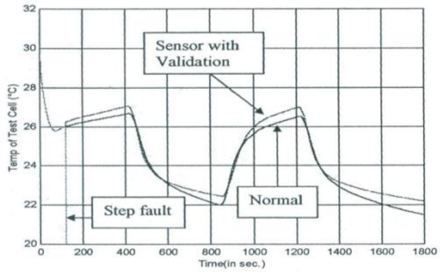

Fig. 4. Sensor Validation Scheme for fault in temperature of Test Cell sensor.

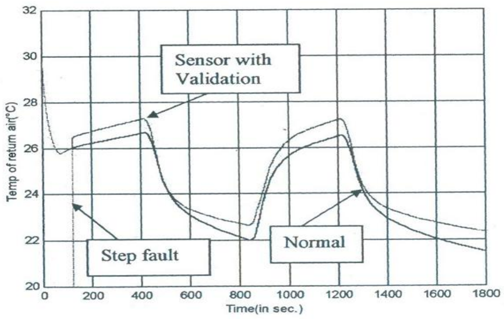

Fig. 5. Sensor Validation Scheme for fault in temperature of return air.

CONCLUSION

The VAVAC system is an essential component of Building Management system and hence undoubtedly a lot of expectation from the associated control system to achieve optimal energy expenditure is obvious while maintaining a desired temperature and other comfort requirement of the given space. In future the VAV controller is expected to meet many performance parameters. The present model for validation will be very useful to validate all or most of the sensor signal used in feedback control. The proposed ANN model will replace the erroneous sensor signal with the estimated or validated signal to be used by the controller for the next time instance.

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