Model Reference Neural Network Control for a Variable-Speed Air conditioner

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Abstract: - This paper presents an experimental study of utilizing a neural network as a controller for controlling a variable-speed air conditioner. An inverter is used for varying the speed of the compressor motor. The controller is a feedforward neural network with two nonlinear hidden layers. A model reference technique with the standard back-propagation adaptation rule is used for training the controller. The reference model is selected such that the control system has the settling time of 50 seconds. The control results are satisfactory. The responses of the neural network control system are similar to that of the model reference as required. Moreover, we compare between the consumption of energy in the neural network control system and that in a conventional fixed speed system. Without consideration of the efficiency of the inverter, the neural network control system consumes less energy than the fixed speed system by approximately 17 %.

Key-Words: - neural network control, model reference technique, air conditioner, variable-speed compressor

1 Introduction

Conventional air conditioners use a thermostat as an on-off controller to regulate the room temperature by turning the compressor on and off. While the compressor is on, the speed of compressor motor is fixed. Advantages of the on-off fixed speed control are, for instance, its simplicity and economical cost. However, it is well known that the on-off air conditioning system inefficiently utilizes electricity due to the on-off cycling losses in the compressor. Since energy consumption directly contributes to environmental problems and the cost of energy production is also growing, the concept of variable-speed air conditioning becomes prudential to energy consumption improvement. Nowadays, research in the area of variable-speed refrigeration and air conditioning systems has been widely conducted [1-4]. Some systems have also been commercialized. The major difference between variable-speed and conventional on-off systems lies within the control of the system cooling capacity. In a variable-speed system the capacity is regulated to match the heat load by varying the compressor speed.

This paper presents an experimental study of utilizing a neural network as a state feedback controller for controlling a variable-speed air conditioner. The controller is a two-hidden layer neural network with five input nodes and one output node. The Model Reference Neural Network (MRNN) technique [5] is used to train the controller. An inverter receives the speed command from the trained controller to drive the compressor motor. The feedback-state consists of the room temperature, the evaporator and condenser tube wall temperatures, and the evaporating and condensing pressures.

2 Air conditioning Systems

The main parts of an air conditioner comprise a compressor, a condenser, an expansion valve and an evaporator as shown in Fig.1 below.

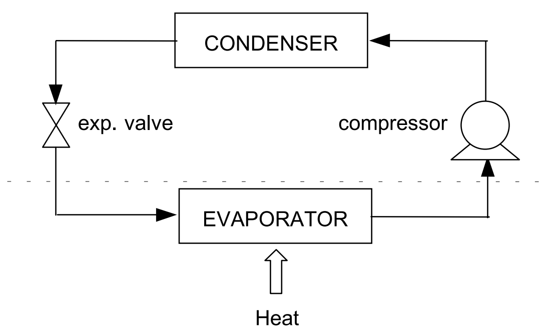


Fig.1 Air conditioning systems

The refrigerant circulating in the system extracts the heat inside the room through the evaporator to lower the room temperature. The cooling capacity varies with the refrigerant mass flow rate, which is a function of the compressor speed. The heat is discharged to the environment while the refrigerant flows through the condenser. The expansion valve reduces the refrigerant pressure to the desired level before entering the evaporator.

3 Neural Network Control

The block diagram of neural network control used in the paper is shown in Fig.2. Here, *X[k]* is the sampled state vector consisting of the room temperature, the evaporator tube wall temperature, the condenser tube wall temperature, the evaporating pressure, and the condensing pressure. The control command $\Omega[t]$ is the speed of the compressor motor. X^* is the desired value of the state whereas Ω^* is the equilibrium value of the compressor speed corresponding to X^*. The neural network controller is a sampled data controller and is trained using a model reference technique described briefly below.

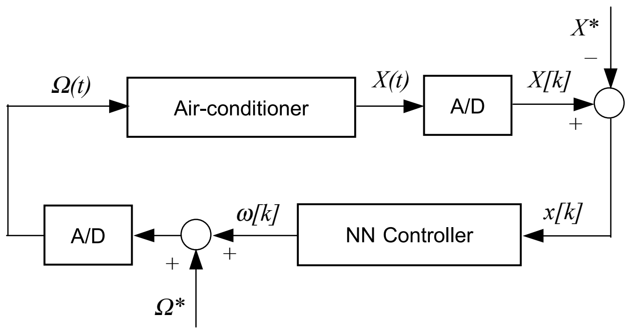


Fig.2 Neural network control system

The Model Reference Neural Network (MRNN) technique [5] is a direct training approach for designing a neural network controller without employing any exiting controller. Only the input-output information of the system to be controlled is needed. The training process consists of two main steps, emulator training and controller training. The emulator which is another neural network is trained to mimic the dynamic behavior of the system or plant to be controlled. Fig.3 shows the emulator training block diagram. After the training process, the emulator is used for estimating the error of the control input. This error is estimated from another error of the system output compared to the output of the reference model and is used to train the controller. The controller training process is described by the block diagram in Fig.4.

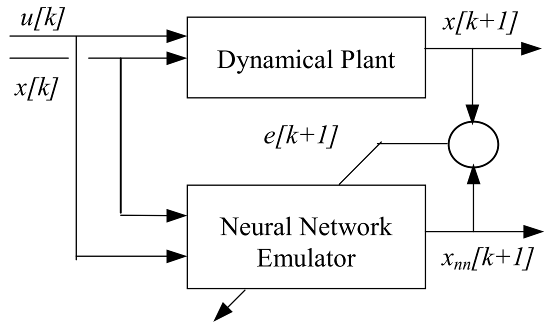


Fig.3 Emulator training diagram

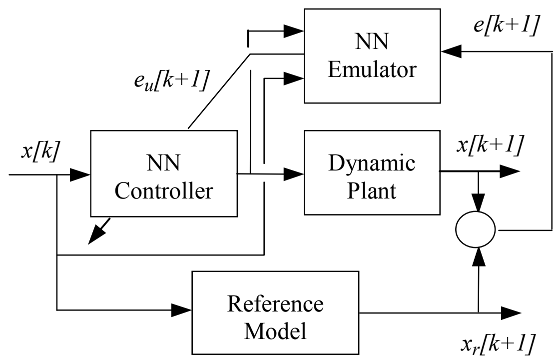


Fig.4 MRNN training diagram

4 Test Facility

The experimentation has been carried out using a 9000-BTU spite-type air conditioning system which is installed in a 3×3 ×2.5 m^3 room. The inverter and the variable-speed compressor used in this paper are illustrated in Fig.5. The room temperature is measured by an LM335-based temperature transmitter whereas the evaporator and condenser tube wall temperatures are sensed by type-K thermocouples. Two stainless steel pressure transducers are used for measuring the evaporating and condensing pressures (see Fig.6-7). The controller is implemented in a PC while the interface is achieved through an analog-digital interface board. All control law is written in C. The control sampling rate is 0.8 Hz.

Fig.5 Inverter and compressor

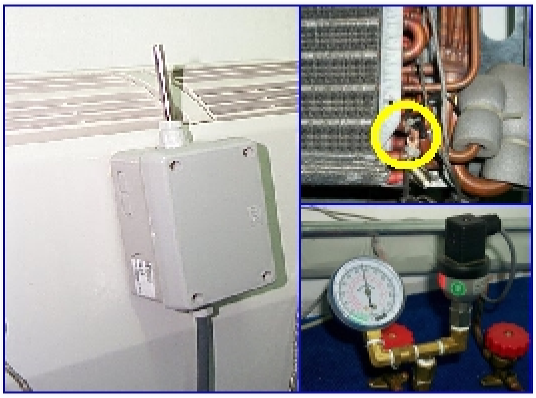


Fig.6 Evaporator and the transducers

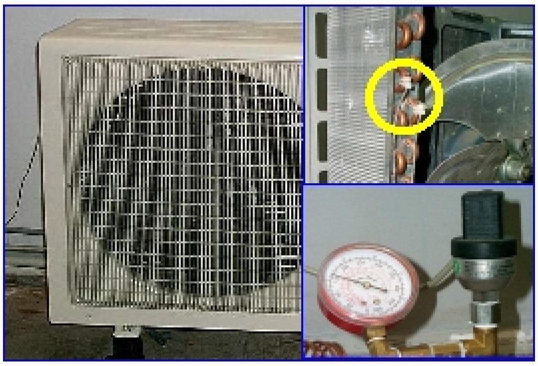


Fig.7 Condenser and the transducers

5 Neural Network Controller

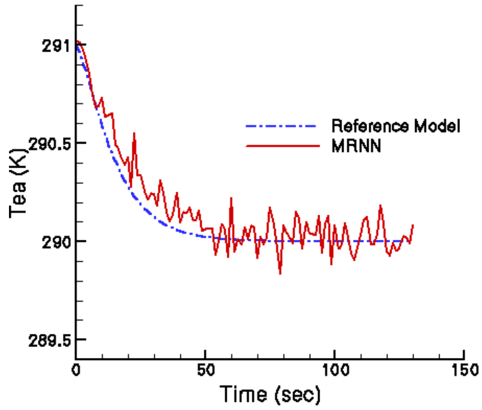
The controller is a feedforward neural network with two nonlinear hidden layers. The number of the input, hidden, and output nodes are 5, 15, 15, and 1, respectively. The MRNN technique along with the standard back-propagation algorithm is used to train the controller. The reference model is selected corresponding to the settling-time requirement of 50 sec. The total 3,000 data points collected from the system with the sampling rate of 0.8 Hz while using a sweep sinusoid function as the input signal are used for training the emulator and the controller. The final RMS-error after training controller is at 0.039. The values of X^* and Ω^* that are used for design the neural network controller are shown in Table 1.

Table 1 Desired state and speed command

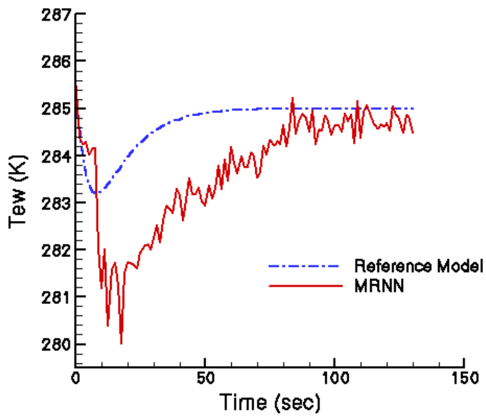
Variables		Values
X^*	T_{room}	290 K
	$T_{evaporator}$	285 K
	$T_{condenser}$	306 K
	$P_{evaporator}$	460 kPa
	$P_{condenser}$	1570 kPa
Ω^*		60 Hz

6 Results

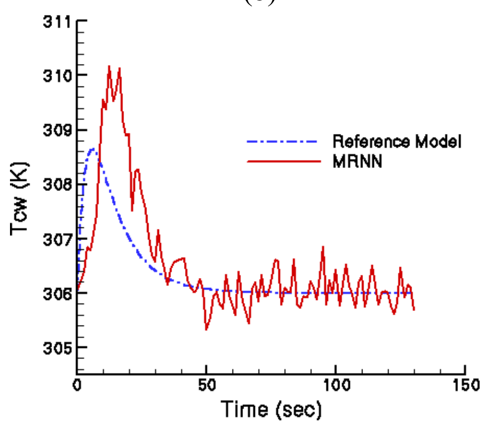
Fig.8 shows the responses of all five states of the MRNN control system compared with that of the reference model. Notice that the response of the room temperature matches the reference model very well as shown in Fig.8a. However, the responses of the other states are slower than that of the reference model. We suspect that the speed of these responses might be limited by the compressibility of the refrigerant and the mechanical inertia of the compressor. Further research is needed. Fig.9 shows the control command.



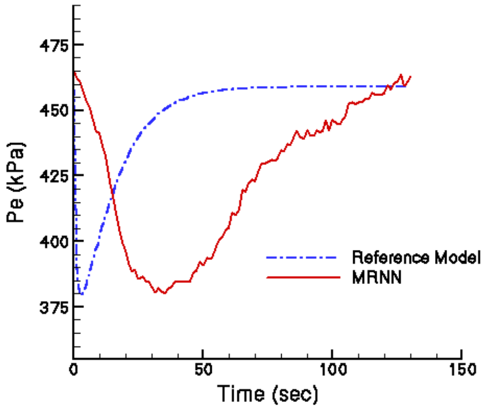
(a)



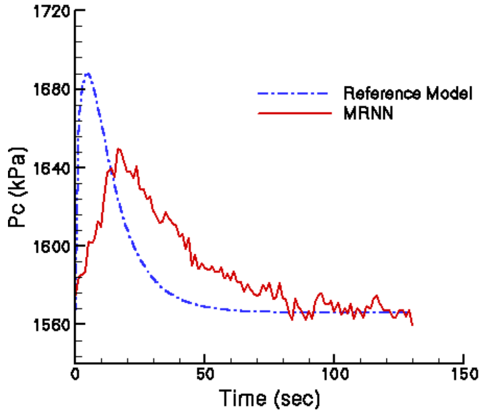
(b)



(c)



(d)



(e)

Fig.8 Control responses: (a) room temperature, (b) evaporator tube wall temp, (c) conden- -ser tube wall temp, (d) evaporating pres- -sure (e) condensing pressure.

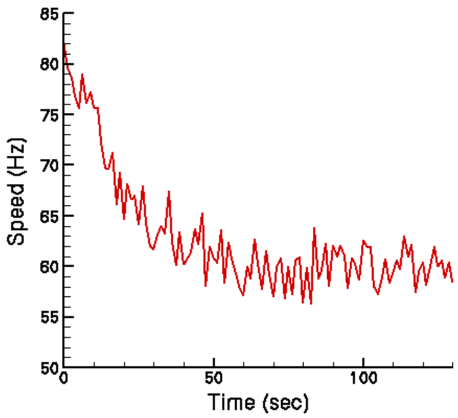


Fig.9 Control command

Moreover, we have also tested the control system with a periodic heat disturbance generated by a heater and compared the results with those using a conventional on-off fixed speed system. However, when we run the on-off system we encounter a noise problem corrupting the measurement data while the compressor is turned on and off. To avoid this problem, the compressor is set to operate at 30 Hz instead of 0 Hz for the "off" state. At the same time, the speed of the compressor at the "on" state is fixed to equal 90 Hz. In Fig.10 the MRNN control system has less temperature fluctuation than that in the fixed speed system as expected. Without consideration of the efficiency of the inverter, the neural network control system consumes less energy than that of the fixed speed system by approximately 17 %. Note that the amount of the energy are obtained directly by integrating the speed command profile (see Fig.11 and 12).

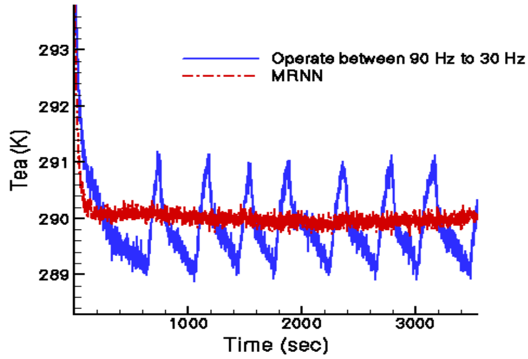


Fig.10 Room temperature

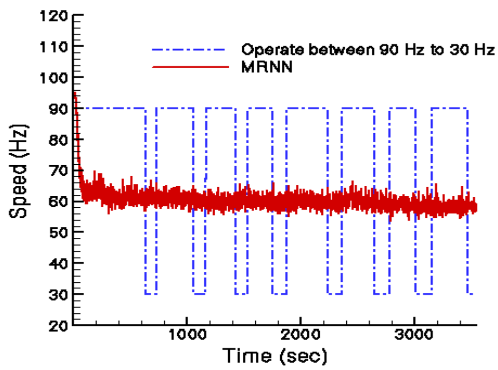


Fig.11 Control command

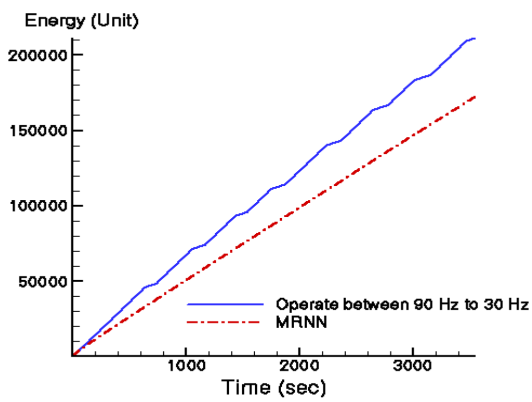


Fig.12 Energy usage

7 Conclusion

An experimental study of neural network control of a variable-speed air conditioner has been presented in this paper. The neural network controller is a two hidden feedforward network trained using a model reference technique. The results show that the responses of the neural network control system are similar to that of the model reference as required. Moreover, when the results are compared with that achieve using a conventional fixed speed air conditioner, the neural network control system consumed 17% less energy. In general, satisfactory results are obtained.

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