

A Low Cost Temperature Conditioning System.

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ABSTRACT: The measurement process of temperature fluctuations in a complex environment is very difficult due to the diffusive and convective phenomena governing a thermal process. As a matter of fact many sensors must be used and very complicate data processing must be implemented to perform a suitable temperature control.

In this paper the realisation of a low cost temperature sensing system to be applied in a heat convector system is dealt with. It can be used in several applications when both economical and good performance tasks must be performed. NTC sensing devices are proposed and a neuro-fuzzy signal processor is used.

Good performances have been obtained by using the proposed system, especially if high rate temperature fluctuations can be ignored.

KEYWORDS: NTC sensors, neuro-fuzzy modelling, low cost application.

INTRODUCTION: AN OVERVIEW OF THE SENSING SYSTEM

Applications requiring temperature control are becoming more and more diffused. Cars and home air conditioning are some examples of such systems. Very often, especially when general purpose applications are considered, optimal requirements in both cost and efficiency must be accomplished. In order to fix this target both the lowest number of sensors and high performances signal conditioning sections must be used [Doebelin, 1990].

In this paper temperature conditioning of a generic environment is considered. The schematic representation of the experimental set is reported in Fig. 1. The H device is a heat-convector and T is the duty cycle of the power supply that is modulated to control the room temperature: the larger the duty cycle, the higher the room temperature.

In order to perform a suitable temperature control, some sensing devices must be placed on the heat convector. Moreover, some sensors must be used to identify the dependence of the room temperature on both the convector heat flux and external temperature. Hence the following sensors have been installed in the investigated system:

S_1 is an NTC sensing device for the measurement of the room temperature T_{amb} in a point P which is 1.5 m far from the convector;

S_2 is an NTC sensing device for the measurement of the temperature T_{sup} on the top side of the convector;

S_3 is an NTC sensing device for the measurement of the temperature T_{inf} on the bottom side of the convector;

S_4 is an NTC sensing device for the measurement of the external temperature T_{ext} ;

By using the information collected by the sensors S_2 , S_3 and the duty cycle T , a model for the estimation of the temperature T_{amb} in the point P can be identified.

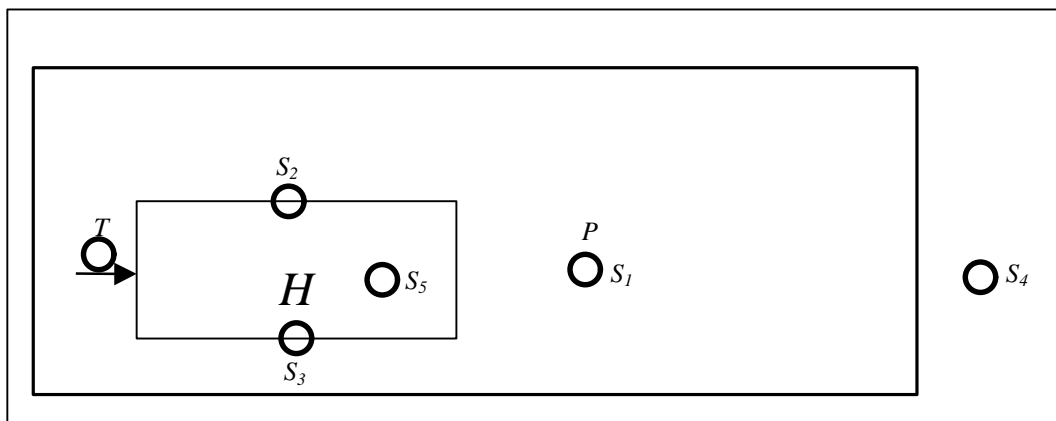


Fig. 1: The experimental set of the considered heating system.

A generic form of the above introduced model is:

$$T_{amb}=f(T, T_{sup}, T_{inf}) \quad (1)$$

The main target of this work is the reduction of the number of system inputs, the optimisation of their location and the identification of a suitable form of the model (1) showing a good estimation capability. It should be underlined the necessity to fit the system performances assuming an accuracy of $\pm 1^\circ\text{C}$ in the temperature range between 8°C and 28°C and of $\pm 0.1^\circ\text{C}$ in the subinterval between 18°C and 22°C .

2. THE NEURO-FUZZY APPROACH.

Many identification techniques could be used for determining a suitable form of the $f(\cdot)$ function. In this paper the neuro-fuzzy approach is proposed because of the complexity of the considered system and the non linear physical law ruling the enquired phenomena [Lippmann, 1987], [Zadeh,1973], [Cybenko, 1989], [Narendra, 1990], [Roseblatt, 1958], [Sugeno, 1983]. In particular the neuro-fuzzy tool ANFIS implemented in the Matlab environment has been adopted.

Three different environmental conditions characterised by different external temperature T_{ext} , reported in Fig. 2, are taken into account. The following model has been investigated:

$$T_{amb}=f(T, T_{sup}) \quad (2)$$

The environmental temperature estimated by means of (2) in case of $T_{ext}=T_{extA}$ is reported in Fig. 3a.

In order to test the efficiency of the model the statistical properties of the residuals have been investigated [Zadeh, 1965]. The data density plot of the residuals, related to the previous estimation, is reported in Fig. 3b As it can be observed, a low estimation capability has been achieved and the required system performances are not satisfied.

By using the T_{inf} information an improvement in the model estimation capability is achieved. The considered model is the following:

$$T_{amb}=f(T, T_{inf}) \quad (3)$$

Both the residuals trend and the data density plot for the model (3) in the three T_{ext} conditions are reported in Fig. 4.

It should be observed that the proposed models cannot fit the high rate fluctuations of the environment temperature T_{amb} due to the external temperature fluctuations. This is because the influence of this quantity can not be physically taken into account in the model. However by considering the problem target these effects can be ignored.

A model using the quantities T , T_{inf} and T_{sup} as inputs has been also tested, but the obtained performance doesn't justify the increasing system complexity.

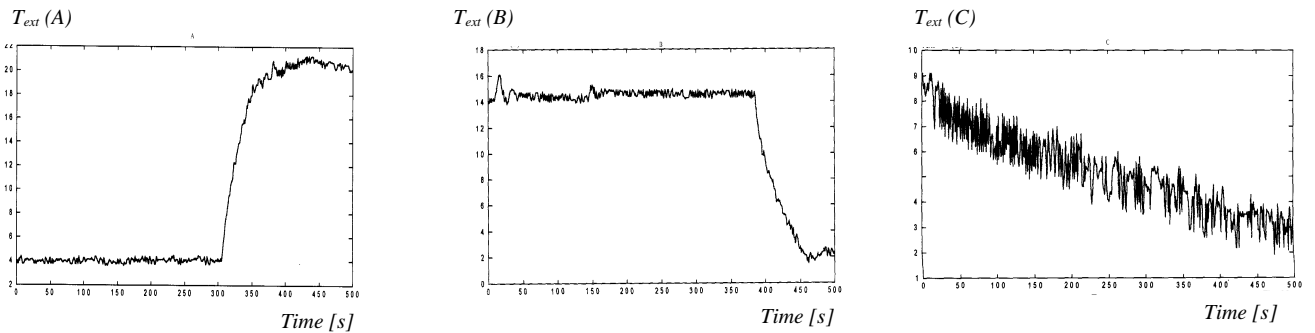


Fig. 2: Three different environmental conditions characterised by different external temperature.

3. A MORE SOPHISTICATED SYSTEM.

In order to improve the efficiency of the proposed system one more piece of information about the energy E associated to the power supply can be used [Doebelin,1990].

The form of the model becomes:

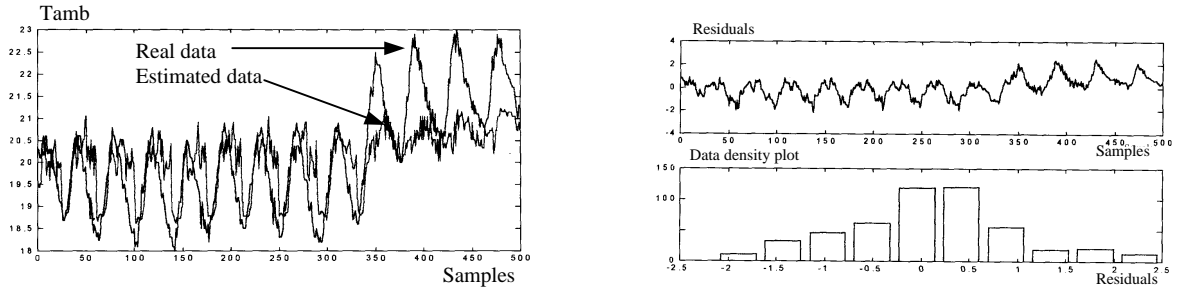


Fig. 3: The environmental temperature estimated by means of (2) in case of $T_{ext}=T_{extA}$

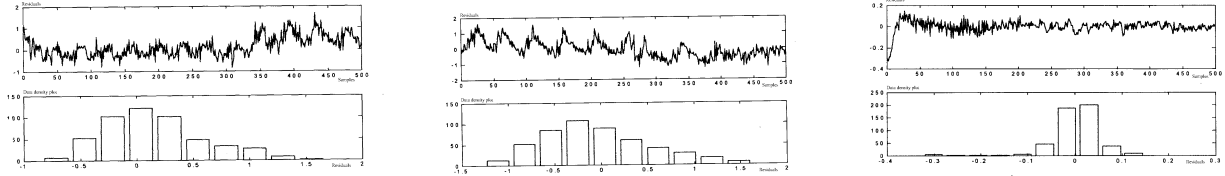


Fig. 4: The residuals trend and the data density plot for the model (3) in the three T_{ext} conditions

$$T_{amb}=f(T_{inf}, T, E) \quad (4)$$

As it is shown, by the data density plot reported in Fig. 5 a good estimation capability is obtained. However, the estimation of the E quantity requires a more complicate sensing structure, leading to an increasing system cost. On the basis of this consideration a different form of the model (4) assuring the same feature during the estimation task would be suitable.

To reach this target, an additional sensor S_5 has been placed in the convector external chassis. The information given by this device is related to the heat transfer T_{ch} through the front panel of the convector and strictly depends on the T and E quantities. The relationship among these quantities appears to be more evident in Fig. 6. In order to show the reliability of this hypothesis this relationship, the T_{amb} estimated by means of the model (4) is compared to the estimation of the same quantity obtained by using the following model:

$$T_{amb}=f(T_{inf}, T_{ch}) \quad (5)$$

The comparison of the residual distribution for the two estimations is presented in Fig. 5. Similar features are observed for both models, confirming the possibility to use the simplified system (5) with two input sensing devices.

The comparison among the models being introduced is reported in Tab. 1. The efficiency of the models can be find out on the basis of the neuro-fuzzy rules number, the input number and the mean square error between the set of real data and the one of estimated data. It should be underlined that the data set used both to train and to test the models is fixed. Models (4) and (5) show the same estimation capability, rather better than model (3). However on account of the other performance parameters model (5) appears to be more adequate.

It should be taken into account that several attempts have been made in order to find both the suitable number and type of the membership functions on all inputs.

The identified model can be easily introduced in the control scheme performing suitable temperature control illustrated in Fig. 7.

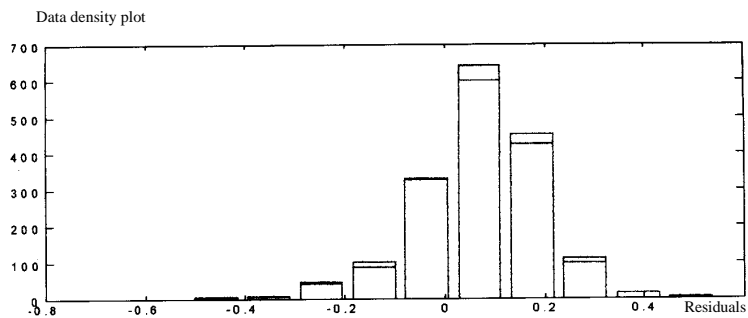


Fig. 5: The comparison between the data density plots related to the models (4) and (5).

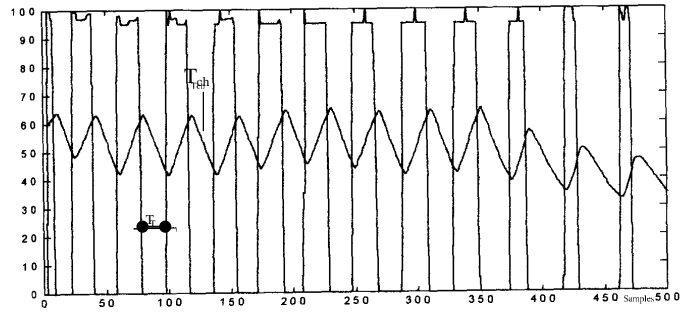


Fig. 6: The relationship among the quantities T , E , T_{ch}

Sensing devices	Output number	Rules number	Mean square error
S_2, T	1	9	0.72
S_3, T	1	9	0.28
S_3, T, E	1	16	0.09
S_3, S_4	1	8	0.078

Tab. 1: The comparison among the models (2)-(5).

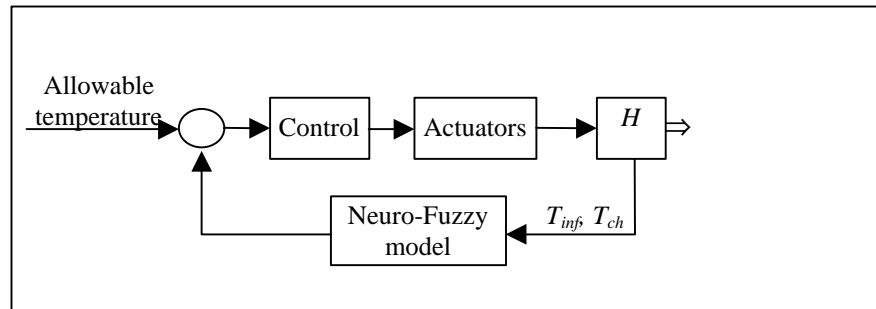


Fig. 7: The control scheme for the heat conditioning system.

4. CONCLUSIONS

A low cost temperature conditioning system has been implemented by using two NTC sensing device and a neuro-fuzzy signal processing approach.

Good performances of the proposed models have been obtained and a very interesting approach allowing temperature control in several real systems has been developed. Moreover the experimental results discussed in this paper have been taken into account for application on industry scale.

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