



Real Time Solution for Inverse Heat Conduction Problem in One-Dimensional Plate Utilizing Fuzzy- Proportional–Integral–Derivative Controller

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ABSTRACT: This paper dealing with a novel algorithm based on features of fuzzy- proportional–integral–derivative controllers to estimate heat flux on the inverse heat conduction problems. The main structure of Fuzzy- proportional–integral–derivative is a proportional–integral–derivative controller in which the proportional, integrator and the derivative gains are obtained online by fuzzy system. The input of the algorithm is the measured temperatures within the model. In each time-step, the smart controller calculates the proper heat flux in order to adjust the measured temperature with the desired input temperature. The model studied a flat plate with an insulated surface and an active level that affects the variable heat flux at the time. The variation of heat flux with time can be considered to be constant, step, and triangular. The measured temperatures are obtained at the active and inactive surface with numerical simulation. The effect of noise level at the measurement temperatures on the accuracy of the proposed method is investigated. The estimations and error analysis indicate that this algorithm is very successful in estimating the different forms of heat flux with different amounts of noise and the different thermocouple positions in the wall. The accuracy of the proposed sequence method is higher than that of the Tikhonov method.

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1. INTRODUCTION

Inverse Heat Conduction Problems (IHCP) have recently found wide applications in industry. In general, methods of solving inverse heat conduction problems can be divided into two main groups: sequential methods and whole domain methods. Each of the groups has its own advantages. Sequential methods can be used for real time estimation and require less memory and computational time [1-3].

Since most of the techniques proposed by researchers are whole domain methods that require all measurement data to be estimated over a specified period of time, this paper proposes an online method based on Fuzzy- Proportional–Integral–Derivative (PID) controller features for heat flux estimation. Here, the algorithm input is the time history of the temperatures measured inside or on the object. These temperature signals contain information about the heat flux applied to the object that can be obtained using the proposed algorithm. At each time step, the intelligent controller calculates the proper heat flux to match the measured temperature with the desired inlet temperature. The accuracy of the proposed method is evaluated by various numerical experiments. In the present study, the effect of control parameters, filter cutoff frequency, data noise and sensor position in heat flux estimation have been investigated.

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2. METHODOLOGY

Consider heat conduction in a 1D flat plate in which one surface is exposed to heat flux and another surface is insulated. Heat flux is unknown and may be changed with time. In this paper, we propose a method for estimating heat flux using the time history of measured temperatures using feedback control systems theory. Intelligent control systems are generally classified into neural networks, fuzzy-neural networks, and fuzzy logic systems [4]. Fuzzy controllers have been widely used in nonlinear problems because of their independence to plant precision mathematical models as well as their robustness to uncertainties. Fuzzy control based on fuzzy rules establishes the relation between input and output variables.

The PID controller is widely used in industrial control systems because of its simplicity and efficiency. The basis of this system is proportional control. Adding integrator gain eliminates the steady state error while increasing overshoot. Derivative gain also speeds up systems with slower response times and reduces overshoot [5]. Consequently, the classical control law of the PID controller is written as

$$q(t) = K_p e(t) + K_D \frac{de(t)}{dt} + K_I \int_0^t e(\tau) d\tau, \quad (1)$$

In the Fuzzy-PID control strategy, the proportional,



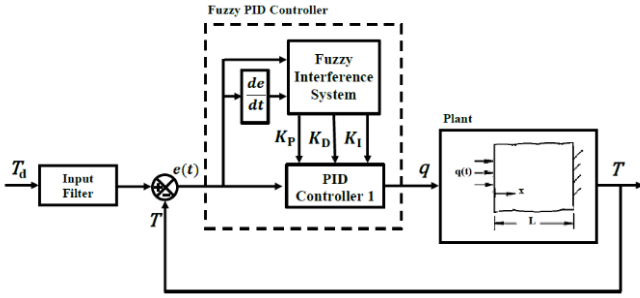


Fig. 1. Schematic of the block diagram of the proposed method

integral, and derivative gains are adjusted online by a fuzzy inference system based on error inputs and error derivatives. The proportional, derivative and the integral gains (K_P , K_D , K_I) are estimated by the aid of the fuzzy logic system which is simply mounted on the classical PID controller [6]. The block diagram of the proposed method is shown in Fig. 1.

3. RESULTS AND DISCUSSION

Several numerical experiments have been designed to evaluate the accuracy of the proposed method. The effect of noise level, thermocouple position, filter cutoff frequency, control parameters, variations of heat flux with time on the accuracy of estimation have been investigated. In the proposed method, the control parameters and filter cutoff frequency are the key parameters affecting the estimation accuracy. In this way, test simulations have been performed to evaluate the optimum selection of these parameters to obtain a more accurate estimation while the sensor is on the active surface. The purpose here is to apply the Fuzzy-PID controller so that it can correctly calculate the input heat flux based on the time history of the measured temperature signal. In this study, three Fuzzy-PID controllers with different control parameters are considered. All of the considered controllers have succeeded in estimating the desired heat flux with good accuracy at the end of the simulation time.

A low-pass filter with transfer function in the form of $1/(1 + s/2\pi f_c)$ was used to estimate the optimum heat flux for the case where the measured temperatures were impregnated with noise. Here the effect of filter cutoff frequency on the simulation results is investigated (see Fig. 2) and the cut-off frequency $f_c = 0.16$ was able to make a good compromise between the system response speed and the heat flux fluctuations and had the lowest *erms* error.

When the thermocouple is placed on the active surface, the estimation is more accurate due to the effects of delay and damping in the conduction heat transfer problem. The proposed method is applied to estimate the time-variable heat flux. The shape of heat flux is considered constant, step and rectangular. The results show that this method can be estimated the shape of heat flux with good accuracy. A comparison is made between the proposed method and the Tikhonov method. In this case, the thermocouple is on the insulation surface and the heat flux is constant. Both methods have been able to estimate the heat flux. The fluctuations in the heat flux estimation using the Tikhonov method are seen

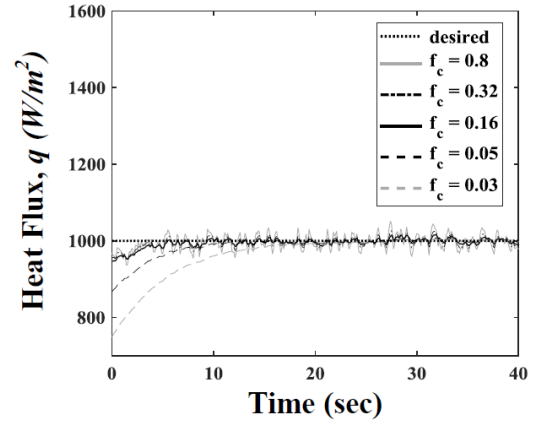


Fig. 2. The effect of filter cutoff frequency on the heat flux estimation

to be higher than the proposed method. Also, the proposed method of this paper can estimate the heat flux with high accuracy only by having the time history of temperature measured up to the present time.

4. CONCLUSIONS

In this paper, a sequential approach is proposed based on the feedback control systems theory in which a Fuzzy-PID controller is utilized so as to estimate the heat flux distribution. The efficacy of the proposed method was investigated for a classic inverse directional heat transfer problem, a flat plate with the insulation and active surfaces. The proposed method does not depend on the mathematical model of the system, so its parameters are set once and then applied to a wide range of input heat flux distribution functions. First, the effect of control parameters and filter cutoff frequency are examined and based on the smaller *erms*, the optimum values for the mentioned parameters are selected and utilized throughout the entire numerical tests. The effect of noise level on measured temperatures, thermocouple position and general form of heat flux on the heat flux estimation accuracy was investigated and error analysis was performed. The results show that the proposed method has been quite successful in all experiments. When the heat flux shape is applied stepwise or triangular, there is a slight delay in the results due to the transient state response of the control system, which is an inseparable part of the present method. Error analysis shows good accuracy of the proposed method in heat flux estimation and can be introduced as a reverse sequence method in heat flux estimation. The proposed method has the potential to be used concurrently with the experiment, which reduces the need for memory and computational time.

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