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Multiple parameter determination in textile material design: A Bayesian inference approach based on simulation

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Abstract

A mathematical model of heat–moisture transfer within textiles and a corresponding inverse problem of textile material design (IPTMD) are reformulated. A stability theorem for the forward problem is given to show wellposedness of the heat–moisture transfer model. A Bayesian inference approach is presented to solve the IPTMD based on thermal comfort of clothing. The triple parameters (thickness, thermal conductivity, porosity of textiles) are simultaneously determined in the sense of the statistical point estimation by the likelihood function. The Bayesian techniques based on Markov chain Monte Carlo (MCMC) methods are employed to simultaneously determine three parameters in IPTMD, where the Metropolis–Hastings algorithm is applied in the inversion process. The interpolated likelihood function reduces significantly the computational cost associated with the implementation of MCMC method without loss of accuracy in the parameters estimation. Numerical experiments confirm that Bayesian inference method can provide more accurate solutions to the IPTMD.

Keywords: Inverse problems; Bayesian inference method; Textile material design; Coupled heat–moisture transfer model; Parameters determination

1. Introduction

With the improvement of people's living standard and the development of science and technology, functional textile materials are increasingly attracting researchers' interests from science and engineering [5,18]. Meanwhile, the thermal comfort of clothing is mostly recognized in the development of new textile materials. Therefore, the design of textile material, based on the needs of human body comfort, is of great significance. In the system of human body–fabric–environment, we usually formulate the heat and moisture transfer process into mathematical models and make numerical simulation for temperature and relative humidity in the microclimate area when the fabric parameters

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Nomenclature

$Ggap$	Generation gap
k_1, k_2	Constants which are related with molecular weight and gas constant
l	Length of Markov chain
L	Thickness of the fabric, m
m_v	Mass flux of water vapor, kg m^{-2} s^{-1}
$Maxgen$	Maximum number of generations
$Nind$	Number of individuals
p_v	Pressure of the water vapor, Pa
p_{sat}	Saturated water vapor pressure at temperature T, Pa
r	Radius of cylindrical pore, m
$RH_0^{i,j}$	Relative humidity in the microclimate area with environmental parameters (T_e^i, RH_e^j), %
RH_{min}	Minimum relative humidity at a specific place during a specific time period, %
RH_{max}	Maximum relative humidity at a specific place during a specific time period, %
RH_e	Environmental relative humidity, %
RE	Relative error, %
T_{min}	Minimum temperature at a specific place during a specific time period, K
T_{max}	Maximum temperature at a specific place during a specific time period, K
T_0	Temperature of the surface next to the human body, K
T_e	Environmental temperature, K
x	Distance from the inner covering fabric, m
Y	Vector of measurements

Greek symbol

π	Probability density
σ	Standard deviation of the measurements
λ	Latent heat of sorption and condensation of water vapor, J kg^{-1}
κ	Effective thermal conductivity of the textile, W m^{-1} K^{-1}
τ	Effective tortuosity of the textile
ε	Porosity of textile surface, %
θ	Vector of unknown parameters
Γ	Rate of condensation, kg m^{-3} s^{-1}

Subscripts

e	Environment
(i)	ith iteration or ith time step
$(*)$	Candidate

are given and hence determine whether the human body is comfortable or not, which is called forward problems [20]. On the contrary, it is called inverse problems to determine the unknown physical and structure parameters of the fabrics according to the requirements of the thermal comfort [19,21,22,4].

Parameters determination in textile material design is a new kind of identification problem [18,21]. Generally speaking, parameters estimation problems are ill-posed since the solution usually does not depend continuously on the input data and any small perturbation in the given data may cause large change to the solution [14]. Therefore, we have to adopt regularization methods to deal with inverse problems. Recently a number of direct search methods have been developed for the inverse problem of textile material design (IPTMD), such as Hook–Jevees (H–J) algorithm [19,22], Golden-Section (G-S) method [21] and Particle Swarm Optimization (PSO) algorithm [2].

Bayesian inference is one of the effective methods employed in solving inverse problem [7,13]. It has been introduced to solve inverse problems such as inverse heat conduction problem [16], heat source estimation in