Identification for Nonlinear Distributed Parameter Systems and Applications on Sea Ice

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Distributed parameter systems (DPSS) are infinite dimensional dynamical systems. Control theories of DPSS are widely applied in many practical problems. We applied the theories to sea ice, fresh ice, transformer, deep-basin gas, paleo-geo and frozen soil temperature fields. The main contributions are as follows:

1. Sea ice is an important indicator and an effective modulator of regional and global climate change.

(1) On the background of thermodynamic processes of snow, sea ice and ocean, one-dimensional and three dimensional piece-wise thermodynamic system of snow-ice-ocean are established, the properties of the two non-smooth systems are obtained, L^2 theory for parabolic systems are used to prove the existence and uniqueness of weak solutions of the two systems; the density, the specific heat, the thermal conductivity and the exchange coefficients of the snow, sea ice and ocean are taken as the identified parameters, the temperature deviation is defined as the performance criterion, and the parameter identification model is put forward; the existence of the identified parameters is discussed, and the first-order necessary conditions for optimality are derived. Thus, the parameter identification theories of non-smooth DPSS are applied to problems of sea ice, and the mathematical foundation for the numerical computation of the parameter identification problems of the sea ice thermodynamic system is provided.

(2) Based on in-situ measurements of sea ice at Nella Fjord around Zhongshan Station, Antarctica in 2006, ice salinity and solar shortwave flux are obtained by parameter identification methods for quasi-linear thermodynamic systems. Results show that better simulations of ice salinity, surface shortwave radiations and temperature distributions are possible than empirical formulae. Therefore the obtained formulae can be applied in sea ice modelling, the method can help in interpreting field data and can be used to overcome data gaps.

(3) A distributed parameter coupled system concerning Arctic sea ice temperature field is established, in which the ice thickness is regarded as a movable inner

boundary of the space domain. The existence and continuity of the weak solution to the coupled system are proved. According to temperature measurements in the Arctic ocean from August, 2003 to April, 2004, we establish a parameter identification model with the ice thickness as control variable and the coupled system as constraints. Finally, an optimization algorithm is constructed on the basis of non-overlapping domain decomposition method and semi-implicit difference scheme. Through numerical calculation, we obtain the characteristics of the ice thicknesses and the ice temperatures.

(4) According to the energy balance equation at the ice bottom, the ice bottom energy balance system has been given. The oceanic heat flux is selected as identified parameter and the ice thickness deviation as the performance criterion, so that the optimal identification model has been presented for the first time. This method to estimate the oceanic heat flux is only controlled by observed ice thickness, which can overcome the calculated bias caused by the technique error of observed temperature and the empirical parameters in other methods. Based on the field campaigns of landfast sea-ice thermodynamic observation off Zhongshan Station in Prydz Bay, East Antarctica in March 2006 to November 2006, time series of the oceanic heat flux and the oceanic heat flux fitting function of time has been derived. The effectiveness of the ice bottom energy balance system has been provided by the sensitivity study on the measurements in the same observation area from May 2005 to November 2005.

2. Fresh ice is a primary factor in the global climate system.

(1) The deviations between the observed and calculated snow or ice surface temperature by assumption and iteration methods have been analyzed for the first time. The nonlinear discrete time delay system for calculating the time delay between the snow or ice surface temperature and the air temperature has been established. Taken the time delay between the snow or ice surface temperature and the air temperature as the identified parameter, the temperature deviation of calculated snow or ice surface temperature and observations is defined as the performance criterion, and then the optimal identification model has been put forward. Based on the field measurements of Finnish lake ice, the numerical simulations show the optimal time delay between the snow or ice surface temperature and the air temperature was one hour.

(2) To notice the difference of the physical parameterization of sea ice and lake ice, snow and ice model is applied in the numerical simulation of Finnish lake ice for the first time. An optimal identification model is established, which contains the freezing date as identified parameter, the observed air temperature and modelled ice thickness as the constraints, to make the snow and ice model can calculate the freezing date. The freezing date identified by the optimal identification model more close to the observation.

(3) The upper and lower envelope of the ice thickness in Hongqi-pao reservoir have been calculated by some simple analysis models. These values can be cite as the reference values for the water project design.

3. Transformer

(1) On the basis of the characteristics of an oil-immersed self-cooled three-phrase transformer, a mathematical model of the three-dimensional temperature field is established. Because the specific heat, density, heat sources and coefficient of heat transfer are discontinuous and non-differentiable, the problem has no analytical solution. We decompose the problem into seven sub-problems, and prove the existence and uniqueness of a viscosity solution for every sub-problem, by combining Perron's method with the technique of coupled solutions.

(2) On the basis of the characteristics of an oil-immersed self-cooled three-phrase transformer(SFZ9-20000/110), a three-dimensional temperature field containing heat transfer and mass transfer is established. Based on piecewise-smooth characteristics of the computation range in a transformer temperature field, piecewise-smooth heat equations in a rectangular and two cylindrical coordinates are established. Penetrability conditions are considered. A multi-domain coupled parameter identification model is constructed. And the existence of optimal solution and optimality conditions are derived. The algorithm and software are given. The numerical results agree the spatial and temporal distributions of the transformer.

4. Deep-basin gas

(1) The formation conditions and distribution principles of deep-basin gas reservoir are different from those of the typical hydrocarbon habitat. The formation and conservation of the gas reservoir must meet the force and substance balance conditions. A numerical simulation method for the system of three-dimensional basin was developed in order to derive the data of geology history from the present data .The numerical result is more exact for optimizing the parameters of the initial porosity and compress coefficients. The mathematical model and algorithm were applied to the research of dynamic distribution and prediction of accumulation quantity of deep basin gas. The numerical results fit well with the practice of Turpan-Hami Basin.

(2)The formation conditions and distribution principle of deep basin gas are different from the typical hydrocarbon habitat. Its format ion and conservation must meet the force and porosity constraint condition. A nonlinear programming model is given to decide the balance depth at fixed time, then the distribution matrix of a region at given time is introduced by solving the nonlinear programming point by point. With the method of geology numerical simulation, the dynamically developing character of deep basin gas can be described. Compared with the former model, the prediction result from our model is more robust because of the introduction of concept of error bound.

5. Paleo-geo and frozen soil temperature fields

(1) A three-dimensional paleo-geo temperature field equation of sedimentary basin and its initial and boundary condition s are established. On the basic of optimization theories, the identification model about some formation of material parameters is constructed and the necessary conditions for the existence of the optimal solution s are given. Finally, an optimization algorithm for the parameters is presented.

(2) Necessity and essentiality of parameter identification of frozen soil temperature field are explained first, based on the practical background, physical property and numerical computation need. Taking a deep ditch in winter as an example, a mathematical model of coupled temperature field is presented, then the distributed control model is given for some parameters in the temperature field equation. Since these parameters are continuous and change slowly, the identification problem in infinite dimension space can be decomposed into several identification sub-problems in finite dimension space. We also discuss the relationship of identification parameters and system solution of sub-problems. At last the existence of optimal identification is proved.