Conformal mapping method and shape optimization approach for an inverse free boundary problem

Masato Kimura (Kanazawa University, Japan)

We consider a simple inverse free boundary problem governed by the Laplace equation. We introduce a conformal mapping method to obtain exact solutions to the free boundary problem and give several examples.

Then we consider a new approach by means of the shape optimization and propose a numerical scheme to solve it using the traction method. The traction method is a widely used numerical scheme for optimal shape design problems in engineering. We numerically check the efficiency of the traction method by using the exact solution which was obtained by the conformal mapping method. We can avoid the numerical difficulty in treating the curvature term arising in the shape derivative of the cost function using its weak formulation coupled with the traction method.

This is a collaboration with H. Azegami (Nagoya U.) and K. Ohtsuka (Hiroshima Kokusai Gakuin U.), and also with my former students [1,2].

[1] Maharani A. U., M. Kimura, H. Azegami, K. Ohtsuka, and Armanda I.:
Shape optimization approach to a free boundary problem.
Recent Development in Computational Science Vol.6,
Kanazawa e-Publishing (2015) pp.42-55

[2] S. Shioda, A. U. Maharani, M. Kimura, H. Azegami, and K. Ohtsuka:
Shape optimization approach by traction method to inverse free boundary problems.
Mathematical Analysis of Continuum Mechanics and Industrial Applications
(Eds. H. Itou, et al.), Springer (2017) pp.111-123.

Unique continuation for Helmholtz equations on the analytic surface

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The problem of extending the solution of partial differential equation from local observation to the bigger domain plays a key role in some practical applications. In this talk, we present our recent results on the extension of the solutions of Helmholtz equation from the open set on the sphere to the whole sphere. The Holder conditional stability estimate is proved based on the complex analysis method. Several possible applications are mentioned. This is a joint work with Faouzi Triki, Yu Chen.

Kernel deconvolution based scattering correction method for x-ray CT

Soomin Jeon (KAIST, Korea)

X-ray CT is one of the most powerful techniques for tomographic imaging. The presence of scatter in raw data (sinogram) leads to reduced low-contrast sensitivity in the reconstructed CT image, also it causes various artifacts such as dark bands and cupping effects. To reduce the scatter artifacts in CT images there have been many researches proceeded, and most approaches are based on the hardware development to make the detector to essentially reject the scattered photon's signal. However, it causes weakness of the overall intensity, resulting in a degradation of the reconstructed image. Therefore, the need for a software-driven approach has been required. However, there have been no standard protocol yet.

In this presentation, I will present a new methodology for extracting scattered signal from the measured signal. We adopt the scattering kernel model of B. Ohnesorge (1999) and M. Sun (2010), and we focus on that how to find the variables that determine the scattering kernel. Reliability and accuracy of the proposed algorithm will be given with the results of numerical experiment.

Sensitivity of fluorescence signal in strong scattering medium with background fluorescence

Goro Nishimura (Hokkaido University)

Non-invasive measurement technologies are key demand in many medical applications and the optical technologies among them are providing some molecular information as well as the structural information and the devices potentially become compact and low-cost. Fluorescence technique is a sensitive method to differentiate some interested regions from other normal regions with help of some fluorescence contrast agents. The depth accessed by this technique can be more than 1~cm from the surface using near-infrared fluorescence dyes.

However, the strong light scattering and absorption by the tissue suffer the fluorescence image reconstruction. In the previous workshops, we discussed some diffuse optics and the frame work to extract optical properties from the measurements. Further, there are many limitations and problems in the real applications. The background fluorescence, which means the fluorescence from unspecific regions, is one of large limitations in the applications; the background significantly degrades the fluorescence signal from some specific locations.

In this talk, we will discuss the background problem. I will introduce the modeling by a Monte Carlo simulation and the sensitivity improvement by selecting a time region of time-domain data.

Short-term estimation of the radiation dose rate by the particle filter

Yuko Hatano (Tsukuba University, Japan)

The radiation exposure to humans is measured by the dose rate, which is in a well-known unit [micro-Sievert/hour]. Since the 2011 Fukushima accident, the dose rate has been measured every 10 minutes on many sites in the eastern Japan.

In the present study, we estimate the dose rate one-day ahead, based on the particle filter. We evaluate the goodness of our estimates by comparing the actual measurements. We also compare the goodness of fitting with other two methods, namely the Kalman filter and the multivariate analysis.

We found that the particle filter gives a better estimate by 20% than the others. As an implementation of the present method, we note the following, in the hope of assessing (and reducing) the radiation risks to the people working outside.

Given a one-day-ahead estimation of the soil water content (that is already on a commercial base), we may provide a one-day-ahead estimate of the radiation dose rate.

Identification of time-dependent convection coefficient in a time-fractional diffusion equation

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In this talk, I will talk about a nonlinear inverse problem for identifying a time-dependent convection coefficient in a time-fractional diffusion equation from the measured data at an interior point for one-dimensional case. We prove the existence, uniqueness and regularity of solution for the direct problem by using the fixed point theorem. The stability of inverse convection coefficient problem is obtained based on the regularity of solution for the direct problem and some generalized Gronwall's inequalities. We use a modified optimal perturbation regularization algorithm to solve the inverse convection coefficient problem. Two numerical examples are provided to show the effectiveness of the proposed method.

Real-time reconstruction of moving directional wave sources from boundary measurements

Takashi Ohe (Okayama University of Science, Japan)

Reconstruction problem of unknown wave source often arises in science and engineering fields such as an estimation of seismic wave sources, acoustic sources, and electromagnetic waves. Many of wave sources have directional properties such as a loudspeaker and dipole antenna.Dipole source model is a mathematical model which describes a directional property of wave source.

We consider the case where some dipoles move in a prescribed domain,and assume that the number, locations and moments of dipoles are unknown. We develop a real-time algebraic procedure for reconstruction of unknown parameters of dipole sources from observations on the boundary of the domain.

We show some numerical experiments, and present the detail of the performance of our numerical procedure.

Shape prior beam hardening correction for industrial 3D conebeam CT

Chang-Ock Lee (KAIST)

X-ray CT's role is growing as demand increases for accurate product quality evaluations at industrial sites. Because it can obtain cross-sectional images inside an object with information measured from the outside of an object, it is useful for non-destructive testing. As industrial technology advances and the complexity of the object to be inspected increases, it is sometimes difficult to determine by itself the images obtained with the inspection equipment. This is because various physical factors are involved in the image obtained with X-ray CT images. Particularly, artifacts due to beam hardening impairs the contrast of the reconstructed image and it results in difficulties in understanding the structure of the object with abnormal values. Therefore solving this is an important issue in the CT technology.

In this talk, we will propose an algorithm that addresses beam hardening in 3-dimensional industrial CT using computer-aided designed (CAD) data as shape prior information. A registration algorithm for 3-dimensional objects will be introduced, in addition numerical experimental results will be delivered with an way to manage the 3-dimensional computation efficiently.

Stability analysis of inverse problems for 1+1/2 fractional parabolic equations

Manabu Machida (Hamamatsu University School of Medicine, Japan)

In this talk, inverse problems for first- and half-order time-fractional parabolic equations are considered. We investigate the stability of inverse source and inverse coefficient problems. The Lipschitz stability is proved using the methodology using Carleman estimates.

On the source identifications for time-fractional order diffusion process

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The inverse problems for time-fractional order diffusion process are novel, in the sense that the fractional order derivative is non-local, and consequently the characteristics of the inverse problems for this system are different from those for classical PDE system. Physically, the time-fractional order diffusion process represents some slow diffusion with tail effect, which have been found in many modern industry and environment areas. In this talk, we will report our joint works with Prof. M. Yamamoto in recent years. We will focus on the linear inverse problems for this system, with the aims of identifying the internal source, boundary source or initial state of the diffusion system from some extra measurement data. The uniqueness of these inverse problems will be proven, and the regularizing schemes together with numerical implementations are also provided.

Fluorescence diffuse optical tomography using a cuboid approximation

Chunlong Sun (Hokkaido University, Southeast University) *clsun@seu.edu.cn*

Goro Nishimura, Gen Nakamura and Manabu Machida

A three-dimensional time-domain fluorescence diffuse optical tomography is numerically investigated based on analytical expressions. The zero-lifetime emission light is analytically calculated by solving coupled initial boundary value problems in the half space. The inverse problem of fluorescence diffuse optical tomography is to recover the distribution of fluorophore in biological tissue, which is solved using the time-resolved measurements on the boundary surface. To reduce the dependence on initial value of algorithm and improve the numerically stability, we propose a reconstruction strategy with two steps; reconstruction with a cubic object first and then with a cuboid object next. The reconstructed results show that it is an effective way to obtain stable and good approximate reconstruction of the geometric information (position, shape, size) and absorption coefficient of fluorophore.

A hybrid Inversion schemes for diffusion optical tomography

Yu Jiang (Shanghai University of Finance and Economics, China) *jiang.yu@mail.shufe.edu.cn*

Inverse diffusion problems appear when we try to find the structure of optical properties of a highly-scattering random medium such as biological tissue using light propagating in the medium of interest. Since the energy density of light in such random media is governed by the diffusion equation in the macroscopic regime, in which the propagation distance of light is much larger than the transport means free path, inverse problems for the diffusion equation are concerned.

Diffuse optical tomography is a medical imaging modality which obtains tomographic images using infrared light. In addition to the ability of finding tumors such as women's breast cancer, function such as brain activity can be studied with diffuse optical tomography. When the absorption coefficient, diffusion coefficient, or both are reconstructed, diffuse optical tomography is formulated as coefficient inverse problems of the diffusion equation. Newton-type iterative methods such as the Levenberg-Marquardt algorithm are commonly used to solve related inverse problems. For these numerical methods to work, it is important to use a good initial guess for the initial value of the iteration. Therefore, the knowledge of optical properties such as the diffusion coefficient and absorption coefficient of the background tissue is necessary. However, in-vivo measurements have to be done in a small region of order 1 mm to investigate optical properties of each organ. Hence although this is a long-standing issue, optical properties in biological tissue are not yet fully understood. Therefore, sometimes it is not easy to set good initial guesses. Solving inverse problems by the Bayesian approach has been sought as an alternative way of obtaining reconstructed images. Although the Markov-chain Monte Carlo approach is in principle able to escape from local minima, it is computationally time consuming and moreover is difficult to find precise values of unknown quantities due to statistical error.

In this talk, we will talk about how to solve the inverse problem of diffusion optical tomography by applying those two inversion schemes.

Reflection principle with applications to unique determination of an obstacle with a single incoming wave

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In this talk we will review reflection principle for some partial differential equations, including harmonic equation, bi-harmonic equation, Helmholtz equation, Maxwell equation and Navier equation etc. The reflection principle gives a non-local extension formula for these PDEs across a hyper-plane under certain boundary conditions. We will show how to apply reflection principle to unique determination of the shape of a polyhedral obstacle in inverse time-harmonic scattering with a single incoming wave. Emphasis will be placed upon uniqueness to inverse acoustic scattering from impenetrable obstacles of impedance-type (Robin boundary condition) and inverse elastic scattering from a rigid body (Dirichlet boundary condition). This talk has been prepared based on discussions with Johannes Elschner.

Carleman estimate on a network for telegrapher's equations and applications

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In this talk, an inverse coefficient problem for telegrapher's equations on a tree-shaped network is discussed. Based on Carleman estimates, we could get local Holder stability estimate for this inverse problem with boundary measurement data. Moreover, a gradient-based iterative algorithm is proposed to solve the inverse problem. Numerical examples are presented to show the effectiveness of the algorithm.

Image analysis technique using FSI-model based AI

June-Yub Lee (Ewha Womens University)

We propose a new methodology of artificial intelligence based on physics model and apply it to medical image analysis. This study includes the mathematical theory of artificial intelligence of multi-layer neural network and explores new application fields. In particular, we will develop a diagnostic technique for coronary artery occlusion using artificial intelligence based on fluid-solid analysis.

The final goal of this study is to build an artificial intelligence system capable of presenting diagnostic index values based on the fluid-solid physical model, beyond the way past medical experts judged the progress of disease based on the degree of stenosis in cardiovascular image information.

Group velocity and wave packet amplitude of flexural wave propagation in one dimensional acoustic black hole structures

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When a flexural wave of the elastic thin plate propagates to a wedge or a pit whose thickness decreases to zero, its wave velocity decreases with amplitude increases and reflection decreases greatly. Approximate analysis shows that the wave velocity may tend to zero, while the amplitude tends to infinity and no reflection. The wedge-shaped structure is considered as one-dimensional acoustic black hole structure, while the pit-shaped structure is considered as two-dimensional one. So far, the phenomenon has been studied by approximate methods such as Geometrical Acoustics (GA). In this study, based on elastic wave equations, acoustic black hole structures are modeled in both 1D and 2D cases and Finite Element Analysis is applied to calculate the group velocity and wave packet amplitude of flexural wave.

Based on comparison with existing approximate analytical results, we analyze our calculation results. Since acoustic black hole structure, as a typical wave manipulation structure, has been widely concerned and studied recently, this calculation may have possible application to an inverse problem.

Balancing principle in supervised learning for a general regularization scheme

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We discuss the problem of parameter choice in learning algorithms generated by a general regularization scheme. Such a scheme covers well-known algorithms as regularized least squares and gradient descent learning. It is known that in contrast to classical deterministic regularization methods, the performance of regularized learning algorithms is influenced not only by the smoothness of a target function, but also by the capacity of a space, where regularization is performed. In the infinite dimensional case the latter one is usually measured in terms of the effective dimension. In the context of supervised learning both the smoothness and effective dimension are intrinsically unknown a priori. Therefore, we are interested in a posteriori regularization parameter choice, and we propose a new form of the balancing principle. An advantage of this strategy over the known rules such as cross-validation based adaptation is that it does not require any data splitting and allows the use of all available labeled data in the construction of regularized approximants. We provide the analysis of the proposed rule and demonstrate its advantage in simulations.

Data modeling in functional clothing design: forward and inverse problems approaches

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Textile material design is of paramount important in the study of functional clothing design. The experimental data shows that there are great challenges in Intelligent Manufacturing in Clothing Industry, such as Thermal Comfort Clothing (TCC) and Thermal Protective Clothing (TPC). The experimental Data varies from the data on clothing parameters, environmental situation, human body comfort Index and skin Injury. Therefore the data modelling of functional clothing design will based on physical model of heat and moisture transfer. The advantages of the data modelling may reduce the design cost and experimental risk.

We focus on revealing heat and moisture transfer characteristics in the system of human body-clothing-environment, which directly determine thermal comfort/safety level of human body. Based on the parabolic model of dynamic heat and moisture transfer, we present inverse problems of textile parameters determination (IPTPD), including thickness, thermal conductivity and porosity determination. Moreover, we mathematically formulate a new space-fractional parabolic model of heat transfer within thermal protective clothing under high environmental temperature- humidity, and the corresponding inverse problems of textile material design are put forward. Some numerical algorithms are presented by the regularization approaches. Theoretical study and numerical simulation results validate the formulation of the IPTPD and demonstrate effectiveness of the proposed numerical algorithms.