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Optical fiber imaging based tomography reconstruction from limited data

E.V. Zakasovskaya*, V.S. Tarasov

Far Eastern Federal University, 8, Suhanova st., Vladivostok, 690091, Russia

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Highlights

- In the article are considered fiber-optical measuring systems.
- Tomography methods reconstruction of distributed physical field parameters.
- Considers the case of parallel non-equidistant measuring lines stacking schemes.
- Two restoration methods are proposed, algebraic and neural-like.
- The approach whose novelty involves measuring network data structuration.
- The results of numerical simulation show that the presented algorithms allow us.

Abstract

The paper discusses tomography reconstruction of distributed physical field parameters by means of fiber optical measuring system based on distributed fiber optical measuring network. Measuring network represents a set of fiber-optical measuring lines stacked in accordance with a certain setup on the surface studied. This work considers the case of parallel non-equidistant measuring lines stacking schemes which requires application of generalized sampling theorems. Two restoration methods are proposed, algebraic and neural-like. The approach whose novelty involves measuring network data structurization for computing process optimization and further application of neural or algebraic technologies to restore a full image of the functions studied is presented.

Keywords: Fiber optical; Distributed physical field; Information measuring system; Measuring lines stacking schemes; Parallel beam tomography; Radial basis function neural network (RBFNN)

1. Introduction

Computed Tomography (CT) [1] has been a research topic for many years [2,3]. In principle, the accuracy and resolution of the image can be made perfect by using an infinite number of noise-free projections because there is a

* Correspondence to: 17-27, Avramenko st., Vladivostok, 690003, Russia.
E-mail addresses: zakasovskaya@inbox.ru (E.V. Zakasovskaya), tarasov_vse@student.dvfu.ru (V.S. Tarasov).

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unique exact inverse of the Radon transform [2]. The aim is to reconstruct a function defined on the plane from a set of one-dimensional projections that are available over an angular range less than the ideal 180°. However, it is not always possible to obtain projective data through a complete set. Incomplete tomographic data sets such as limited view or missing data represent a well-known challenge for CT reconstruction algorithms, since they unavoidably lead to substantial images. Limited data tomography [3,4] is a problem that arises in a number of applications, including medical imaging, nondestructive evaluation, geophysical exploration, holography, and fiber optics. It is an inverse problem that is inherently ill-posed [5].

Continuous development of science and engineering requires perfect measuring technologies. Parameters estimation of the distributed physical fields (PFs) subjected *a priori* to unknown external action is of exceptional importance. This prompted us to create specialized measuring means with sensitivity distributed in space. Similar problems show ample opportunities when fiber optical measuring systems (FOMS) based on distributed fiber optical measuring networks (FOMN) are used [6] (Fig. 1).

In such measuring systems the optical signals acting on fiber optical measuring lines (MLs) [6–8] change proportionally to the volume of external physical influence. Each ML represents the continuous sensitive section of an optical fiber path receiving external influences (Fig. 1).

The output signal of a ML represents a linear integral vs. function of distribution parameter of a PF. In this way we face a problem of reconstructing a function f of distributed PFs against their finite number of linear integrals, f, and mathematically this problem belongs to tomography [1–3,5]. As a rule, the amount of information channels such problems demonstrate is less than the number of parameters under review [1–7]. Therefore, solution of the incorrect problem requires application of special methods. Today a great number of computing methods to process tomographic data is developed, but no method present in the area of an inverse problem solution shows satisfactory results yet.

All methods of tomographic data restoration fall into the following basic groups:

(a) *Algebraic methods with pseudo-inverse techniques* [9,10]. The practical results show that the pseudo-inverse method proves to be the weakest one, and cannot be used all by itself for problem solving requiring high accuracy.

(b) *Analytical methods.* This method describes the inversion of the basic integrated Radon transformation as a filtration of back projections (FBP) [3,11]. The classical FBP method is relatively precise, but it requires information of a large number of projections.

The application of conventional analytic-based algorithms such as FBP to sparse data can result in prominent streak artifacts because they require densely sampled projection data. To obtain such information is often difficult, sometimes not at all possible. It is unacceptable for FOMS, as it results in significant material costs and technical difficulties.

In addition, FBP is not adaptable to irregular ill-assorted measurement information. Unfortunately, this approach is not suitable in FOMS where the number and orientation of the MLs are restricted by the FOMN geometry.

(c) *Iterative methods* [2,3,12,13]. By using ART (Algebraic Reconstruction Technique) [2,3], the evolution theory [14], wavelet transform [15], convex projection method [16], total variation [17], and metric labeling [18] reconstruction can be done without causing defect using ten projections only.

All works we have described above are iterative methods. Iterative methods consider the reconstruction problem as a discrete linear system where projection data is a weighted sum over the image pixels [1,3]. A typical solution is ART in which the reconstruction is accomplished by iteratively updating the estimation of the reconstructed image so that the error between the measured and calculated projection data is minimized. The basic ART updates the reconstructed image and converges to a least squared error solution that can be very noisy for limited data reconstruction [19]. Various improvements have been introduced to the ART.

The iterative ART algorithm modified by the authors [20], works well when additional *a priori* information on a reviewed function is involved. This method is dependable for impact point restoring on a PF, though it is no good for precise impact magnitude determination. Further updating can make it possible to use the method, for example, to restore non-negative smooth functions. To obtain more precise information on complex systems' functioning as is the case with finding a point and magnitude of impact on a PF through FOMS requires special processing methods to be applied.

(d) *Methods based on algorithms of neural networks* [21,22]. All traditional restoration methods depend heavily on the accuracy of underlying generative models. In solving the nonlinear tomographic problems one has to adapt the existing algorithms to the experiment conditions which, as a rule, leads to growing requirements to computational capacity and to simultaneous reduction of reconstruction accuracy. In reality the ML paths, the magnitude and nature of the investigated object parameter on the integral signal magnitude can vary which also lowers the accuracy of reconstruction by the afore-mentioned methods.