Advances in Inverse Transport Methods and Applications to Neutron Tomography

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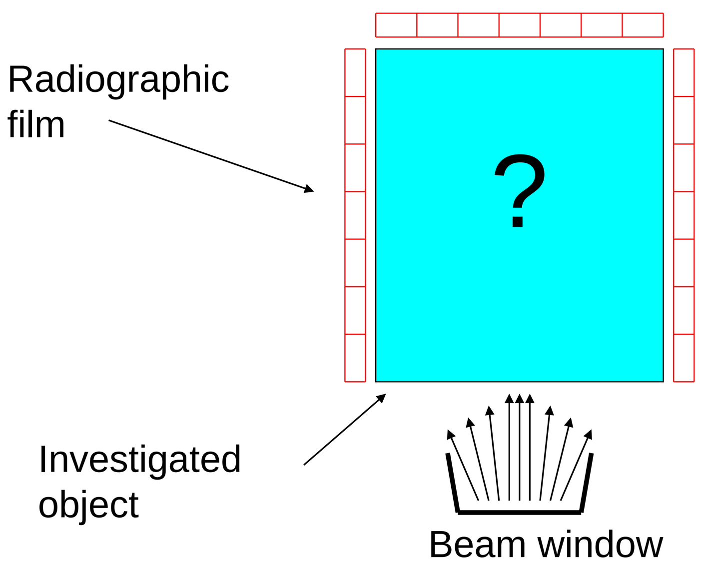
Abstract

We present advances in inverse transport methods and demonstrate their application to neutron tomography problems that have significant scattering. The main advances are dimension-reduction schemes that we have designed to take advantage of known and postulated constraints. One key constraint is that the cross sections for a given region in the object must be the cross sections for a real material. We illustrate our approach using a neutron tomography model problem on which we impose reasonable constraints, similar to those that in practice would come from prior information or engineering judgment. The results shows that our method is capable of inferring correct material distribution in investigating object.

Introduction

The purpose of our project is to infer material distribution inside an object based upon detection and analysis of radiation emerging from the object.



Gradient-based Deterministic Optimization Method[1,2,3]

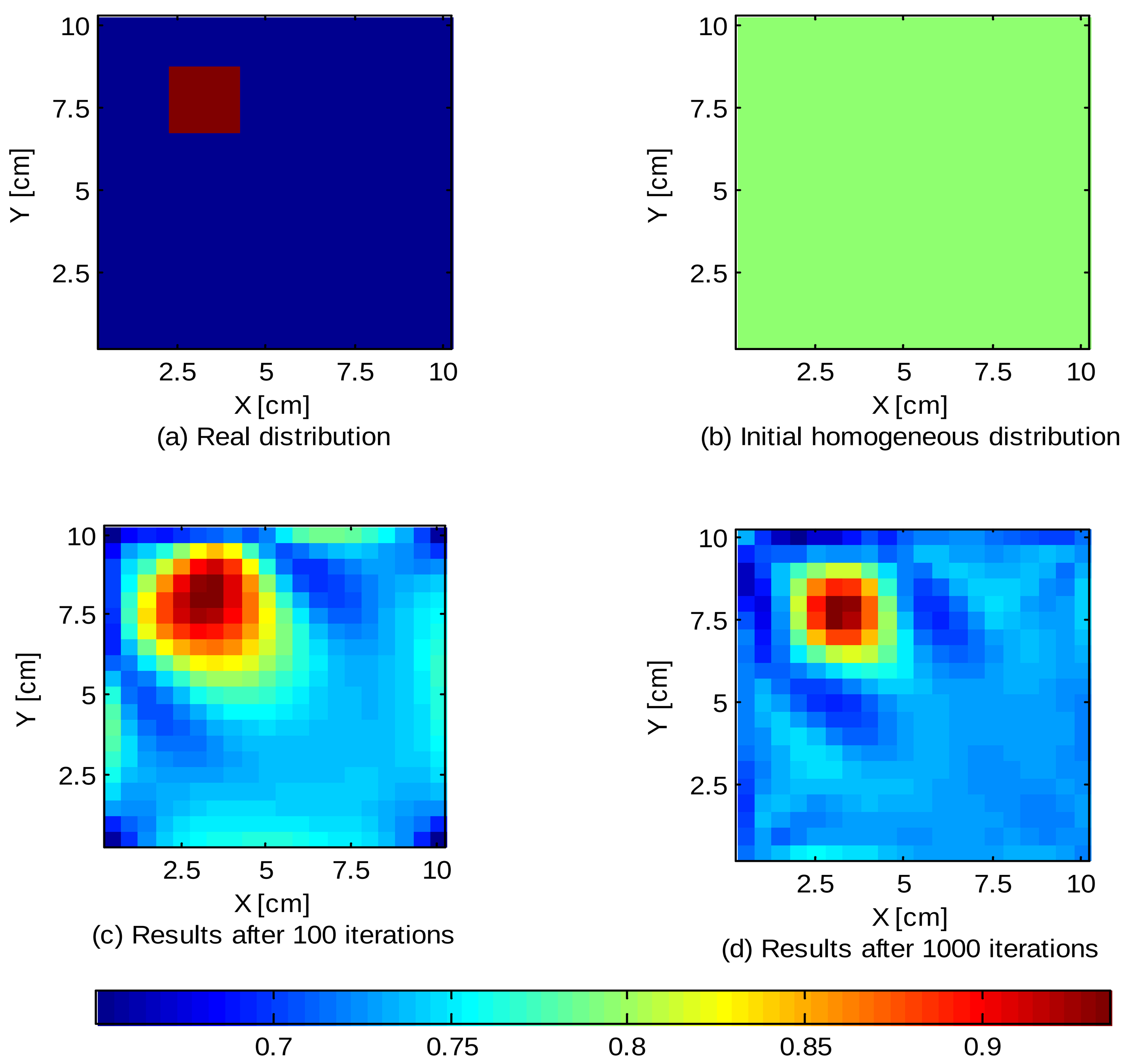
Objective Function:

$$\Phi = \frac{1}{2}\sum_{n=1}^{N}\left(M_n - P_n\right)^2$$

Here 'M' is experimental measurements provided by accurate mathematical model and 'P' is predicted measurements provided by forward model calculation with assumed material properties. P is treated as a function of properties of the unknown object, so as the objective function Φ.

$$P = P\left(\sigma_t, \sigma_s, \sigma_{s1}, \cdots\right) \Rightarrow \Phi = \Phi\left(\sigma_t, \sigma_s, \sigma_{s1}, \cdots\right)$$

Deterministic Optimization Result for Model Problem



(a) Real distribution
(b) Initial homogeneous distribution
(c) Results after 100 iterations
(d) Results after 1000 iterations

Stochastic-based Combinatorial Optimization Method

We treat unknowns as materials instead of cross sections and change continuous search to discrete search in this stage. We use information gained from pervious stage, hence we combine deterministic and stochastic optimization method to work together. We devise a series of novel dimension reduction techniques (cell grouping and material restriction) to mitigate the difficulty of stochastic optimization and develop an efficient combinatorial optimization scheme to achieve the desired results.

Stochastic Optimization Result for Model Problem

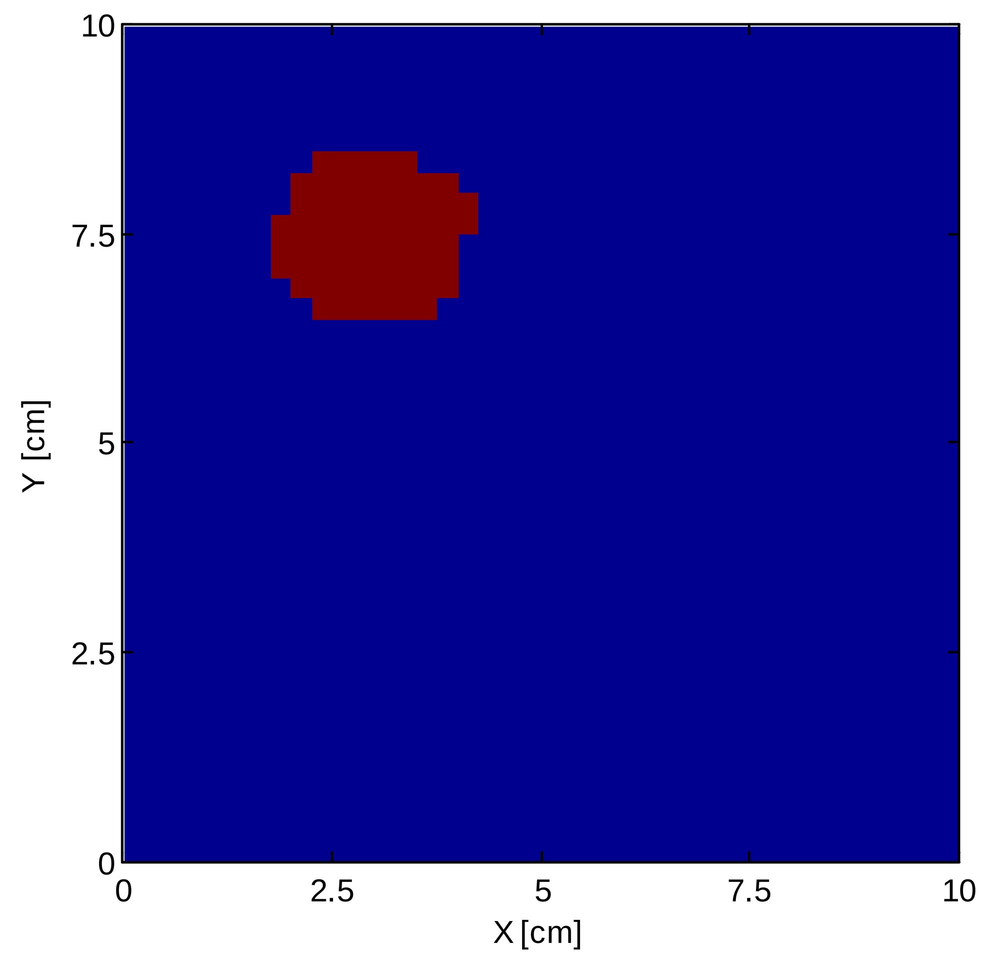


Figure on the left:

Material distribution from the combinatorial optimization after 50 iterations. (Color in this figure denotes material only, not any particular numerical value.)

Table on the right:

Quantitative results of the inclusion location and area with comparison to the real problem

Parameter	Actual	Opt. Result
Material	Iron	Iron
X-center (cm)	3.00	2.97
Y-center (cm)	7.50	7.49
Area (cm^2)	4.00	4.00
Iron/Water	4.17E-2	4.17E-2

Summary

We have introduced some advances in inverse transport methods and applied them to solve 2D neutron tomography problems. Our main idea is to employ multiple steps that work together to dramatically reduce the difficulty of the optimization problem that ultimately produces an estimate of the material distribution in the object being investigated. Results from a simple model problem illustrate the potential power of these ideas. An optically thick problem with a high scattering ratio is solved almost exactly with very modest computational Effort.

References

[1]. V. Scipolo, Scattered neutron tomography based on a neutron transport problem, Master Thesis, Texas A&M University, 2004

[2]. A. D. Klose et al., Optical tomography using the time-Independent equation of radiative transfer - part 1: forward model, J. Quant. Spectrosc. Radiat. Transf. , 72, 691-713, 2002

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18th International Conference on Nuclear Engineering
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