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Two-level refined direct method for electromagnetic optimization and inverse problems

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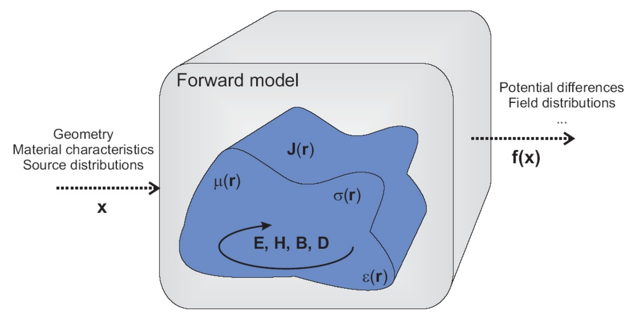
INTEC

Introduction

Forward electromagnetic models:

Numerical techniques (FEM, FDM,...)
CPU-time mainly depends on discretization
CPU-time demanding

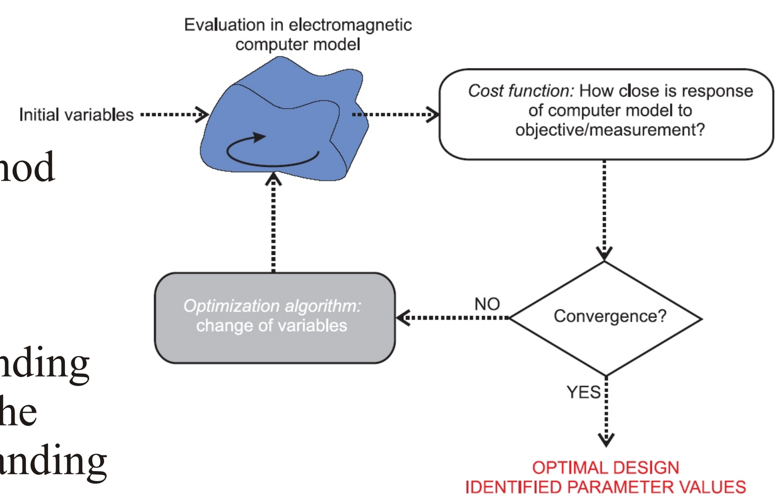


Electromagnetic Optimization and Inverse Problems:

Direct minimization method:
- Iterative solution procedure
- Update of variables depends on method

$$\mathbf{x}_f^* = \arg\min_{\mathbf{x}} \mathcal{Y}(\mathbf{f}(\mathbf{x}))$$

Traditional methods are CPU-time demanding because many iterations are needed and the forward model evaluations are time demanding



Include models with different levels of fidelity into the iterative procedure

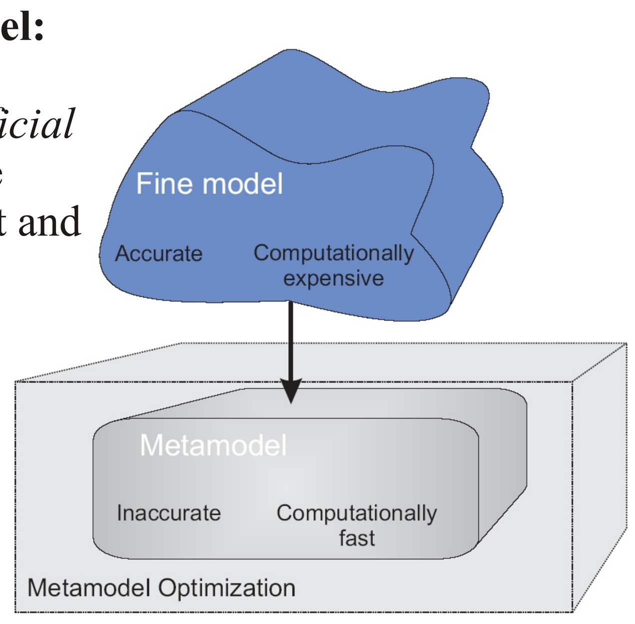
Two-level refined direct method

Construction of metamodel based on forward model:

- *Metamodel (Response Surface Model, Kriging, Artificial Neural Network)* can be constructed from a CPU-time expensive forward model by fitting 'off-line' the input and output space of forward model.

- *Design of experiments* determines which parameter values to evaluate in fine model.

- *Optimization* can be carried out using this computationally fast metamodel.



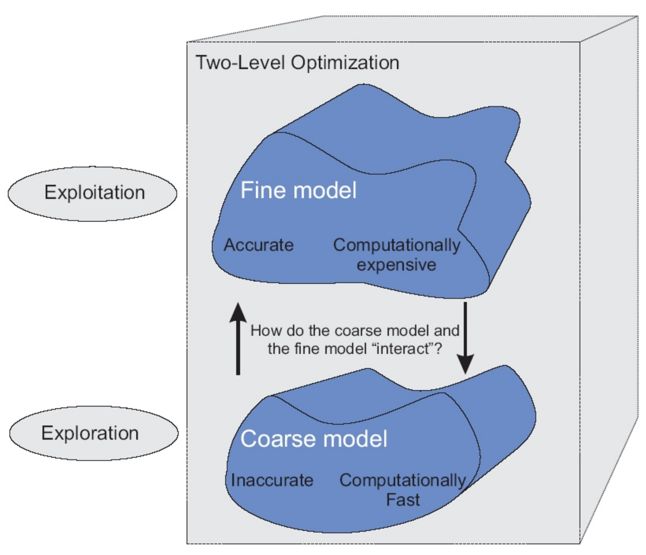
- During optimization, the metamodel can be refined by additional fine model evaluations, see e.g. Efficient Global Optimization (EGO) algorithm.

Difficult when dealing with high-parametric models and with high-nonlinear models

Two-level minimization methods:

- *Coarse model:*
  - approximation of fine model (analytical, coarse discretizations of numerical method, ...)
  - physics-based model
  - Non-linearities of fine model are also available

- Space mapping, manifold mapping, response and parameter mapping: Iterative minimization of coarse model for different objectives



CPU-time demanding when coarse model is not sufficiently faster than fine model. This is the case when coarse model = fine model with coarse discretization.

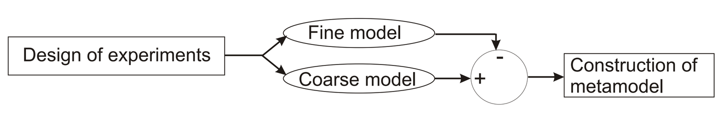
Two-level refined direct method:

- Use of 3 models: *coarse model, fine model, metamodel*

Build computer models:
Fine model: fine discretizations
Coarse model: coarse discretizations

Coarse model can be easily build by using a low number of discretizations in the numerical fine model

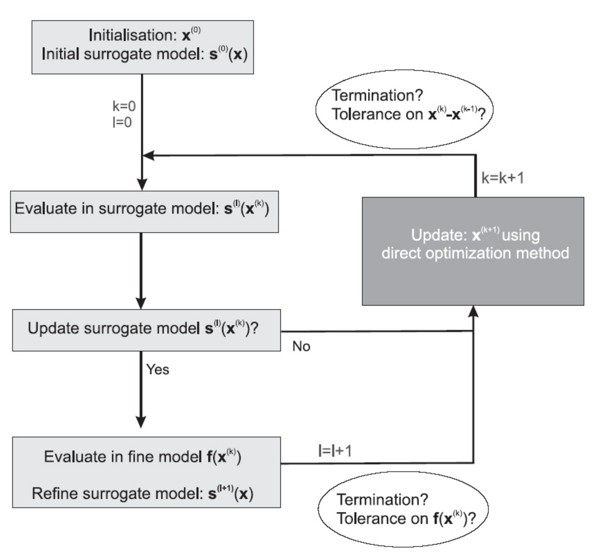
- Metamodel interpolates between coarse and fine model outputs. The high-nonlinearity and high-parametric fine model is approximated by the following *surrogate model: metamodel-corrected coarse model*.



Parallel computing environment can be used in sequential minimization scheme

- Surrogate model is used in each iteration of the direct minimization method. The surrogate model is *refined* during the iterative procedure.

- *Trust region strategy* for determining when surrogate model needs to be updated.



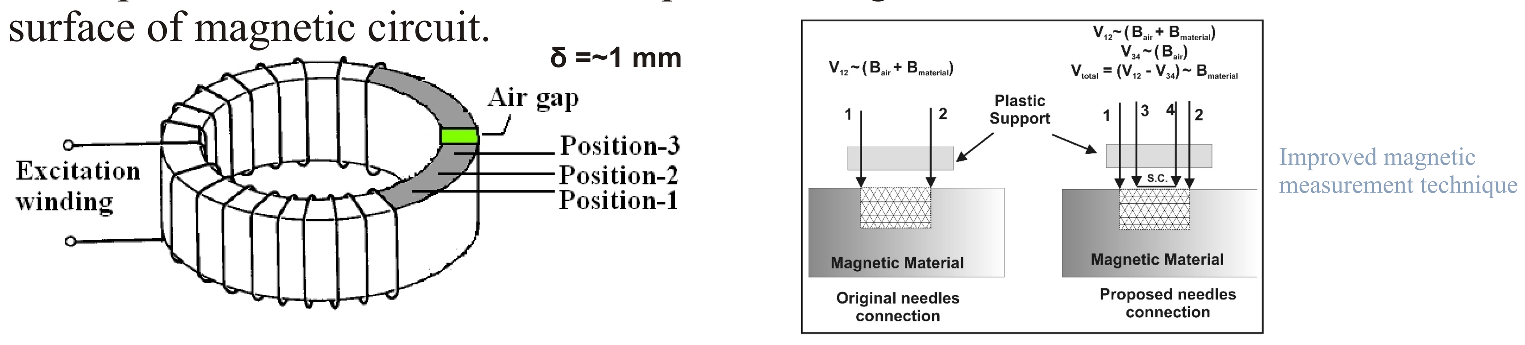
CPU-time efficient solutions of electromagnetic optimization and inverse problems for highly nonlinear problems and high-parametric optimization problems

Magnetic material characterization

Problem: Magnetic materials of electrical machines are often not known.

Solution: Identify the material characteristics by solving an *experimental-numerical coupled inverse problem.*

- **Experiments:** Local magnetic induction measurements: *needle probe method* that measures potential differences, which depend on magnetic material characteristics, on the surface of magnetic circuit.

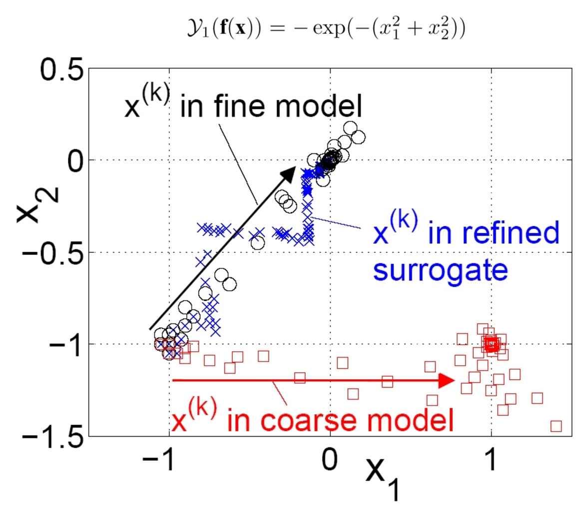


- **Numerical method:** Finite element method with *input:* excitation current, material characteristics. *Output:* Needle voltage signals.

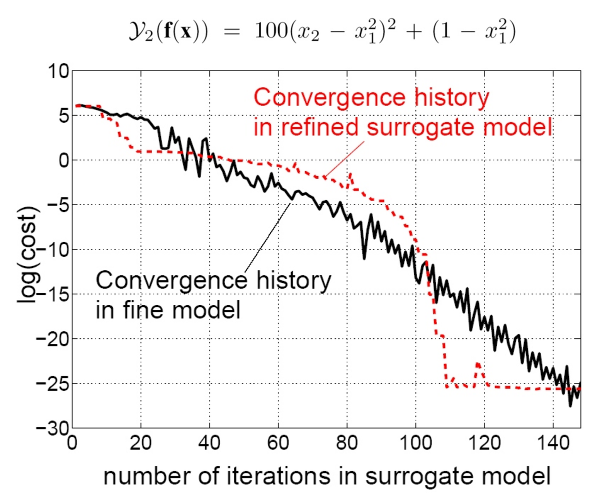
Validation of procedure: Identify the material characteristics on a ring core (simplified electrical machine) with known geometry and material characteristics.

Results and discussion

Application of algorithm on ***algebraic test functions:***



$$\mathbf{x}_s^* = \mathbf{x}_f^*$$



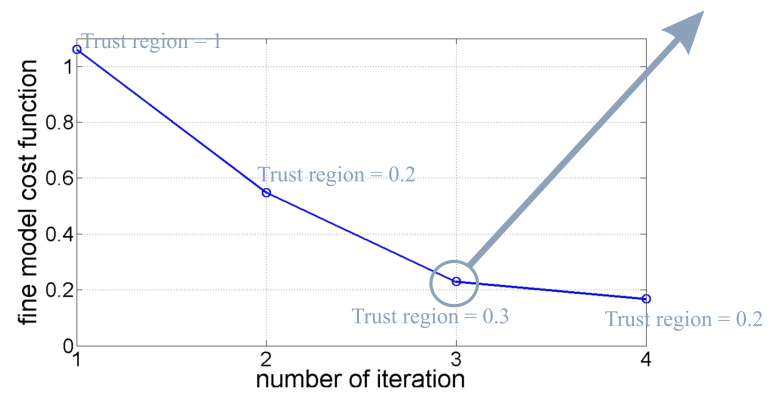
Fine model: exponential model, optimal value [0,0]
Coarse model: altered fine model, optimal value [1,-1]
Metamodel: Kriging model

Fine model: 2D-Rosenbrock function
Coarse model: altered fine model
Metamodel: Kriging model

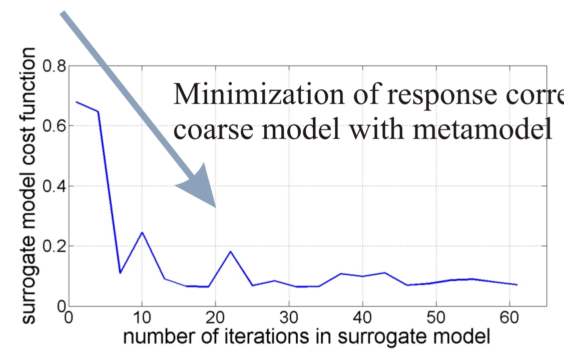
Application of algorithm for ***magnetic material reconstruction:***

Single-valued nonlinear constitutive relation of magnetic material is determined by $[H_0, B_0, \nu]$: $\frac{H}{H_0} = \left(\frac{B}{B_0}\right) + \left(\frac{B}{B_0}\right)^{\nu}$

12 evaluations are carried out in fine and coarse model in a specified trust region.

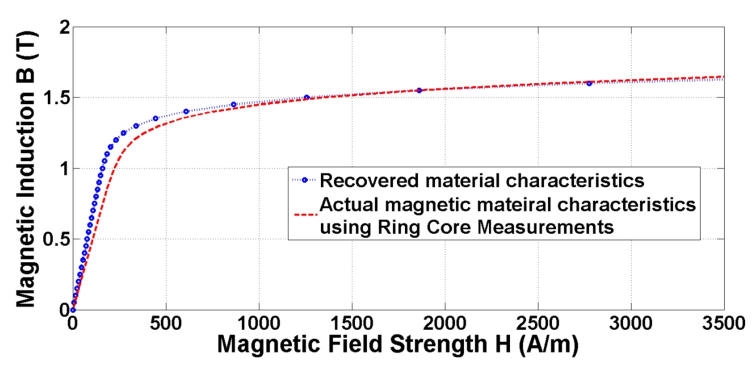


Convergence history of the RCD method



Convergence history of surrogate model at iteration 3

Recovered *BH*-characteristics using RDO-scheme:



Validation of the proposed method:
Recovered material characteristics are close to actual material characteristics of the magnetic circuit

Errors are due to noise in measurements and errors in forward modelling

Computational time: 60 fine model evaluations, 264 coarse model evaluations

Advantages:

+ Parallel computing is possible in a sequential direct minimization scheme
+ Initial computation using coarse model can be used as preconditioner for fine model
+ Fast optimization scheme

Conclusions

- Two-level refined direct method is efficient for optimization and inverse problems with forward models that are CPU-time demanding
- Coarse models for RDO can be easily constructed: fine model with coarse discretizations
- Acceleration for recovering the inverse solution
- *BH*-characteristics of a magnetic circuit can be obtained by interpreting the local magnetic measurements using an inverse procedure
- Validation of an experimental-numerical coupled inverse procedure for magnetic material characterization