Optimisation and simulation – with applications in industry and medicine

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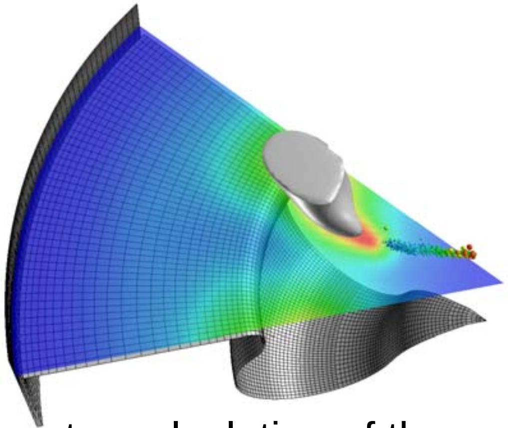
Combustion engine optimisation

A cooperation between GMMC, VCC, and Volvo Powertrain

Goal: develop a better methodology for robust combustion engine optimisation based on CFD and mathematical optimisation algorithms

- 6 parameters (cylinder design & control): swirl number, spray angle, tip protrusion, hole diameter, hole length, and flow number
- 4 objectives: maximise efficiency
  minimise NO_x, soot, and $(dP/dt)_{max}$
- 3 load cases: 1500, 2000, and 4200 rpm



A sector calculation of the cylinder of a combustion engine. The droplets consist of fuel and their colors indicate their temperature. The grey object is an isosurface for the concentration of soot and the plane with a coloured contour plot illustrates the fuel concentration.

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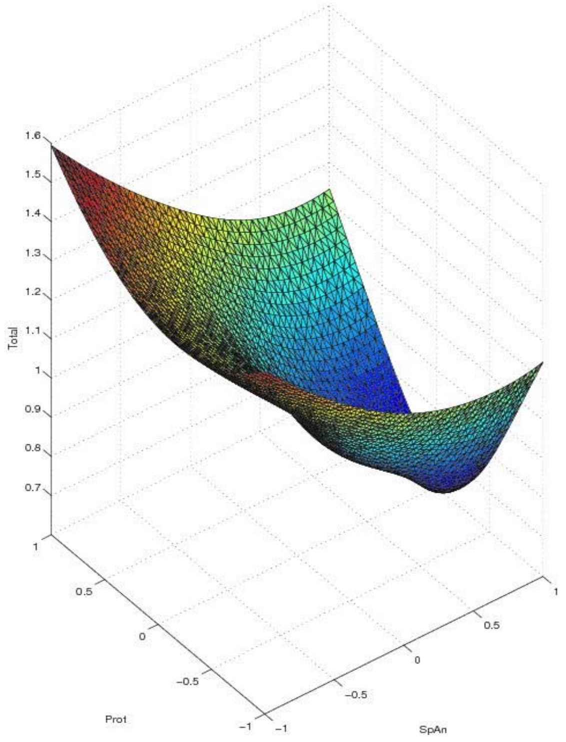
Results so far

1. Preliminary analysis of data from VCC
   Linear Regression, Frobenius & RBF interpolation
2. Used RBFsolve to generate input data for simulations performed at VCC
3. Studied the results with respect to Pareto optimality of objectives
4. RBF interpolation of the results

   Analysis of response surfaces
5. Modification of goal function to avoid unphysical results

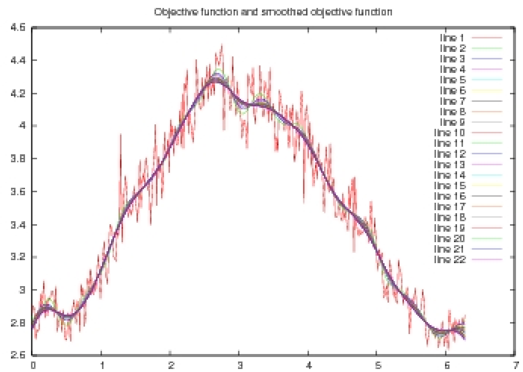


- Only very few simulations possible at VCC

  ⇨ test of algorithms via other real cases of simulation based optimisation

Simulation based optimisation—plan for continued project

Four desired properties of an efficient optimisation algorithm:



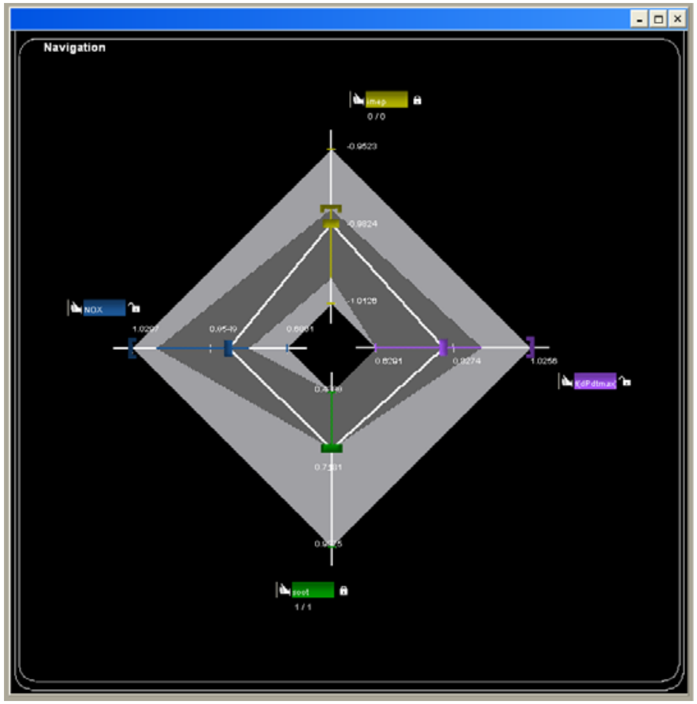
1. Scaling of variables: Methods to find relative variations in different variables
2. Not too sensitive to numerical errors: Approximation instead of interpolation
3. Indicators for convergence and numerical errors
4. Good method for finding new evaluation points

- Radial Basis Functions offers an efficient way to interpolate scattered data
- Use native space norm for the basis function
  ⇨ address properties 1–4 in a consistent way
- New evaluation point is defined as optimum for a function which includes both quality measures and function values of the current approximation

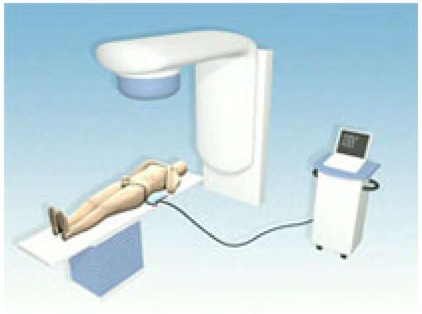
Existing methods: RBFsolve, EGO, newUOA, SQP, MultiOb

Simulation based optimisation—plan for continued project

- Adapt optimisation methods to multiple objectives
- Perform further simulations at Volvo Cars and Volvo Powertrain
- Powertrain performs DoE
  ⇨ data analysis at FCC



Positioning System Optimisation



- Project with Micropos Medical AB

Objective: Develop methodology and software for CEM simulation of wave propagation in the human body, develop methodology and software for CEM-based optimal design, and to apply the result to the design of an antenna system for accurate positioning of cancer tumours to support efficient radiation therapy

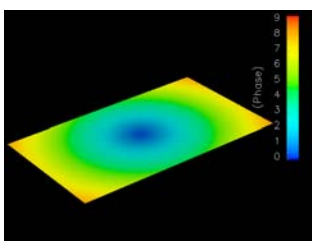
- Methodology: Use the hybrid FDTD–FEM solver developed in the GEMS project

Research topics

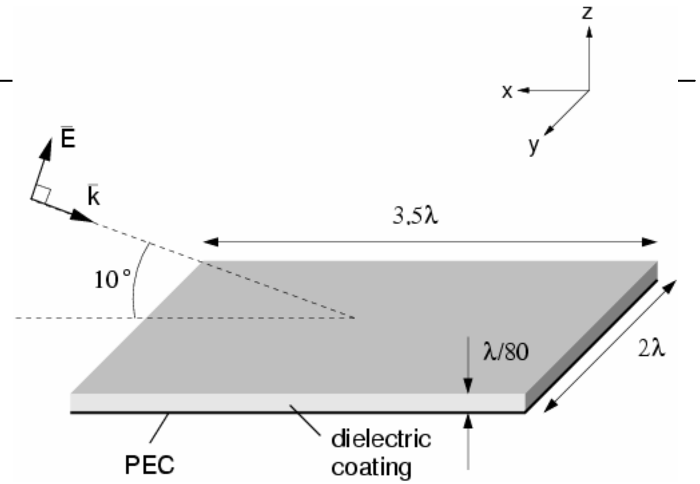
- Find a suitable frequency that facilitates accurate tumor positioning
  - If frequency is too low phase difference is negligible
  - If frequency is too high too much noise (inner reflections)
- The multi-scale character of the problem requires subcell models
  - A thin sheet model is needed to be able to model different materials in the treatment table
- Investigate if a high level of detail model of the human being is needed or if simpler models can be used
- For the modeling of the antenna system a novel coupling of the hybrid solver with a circuit simulator (SPICE) will be considered

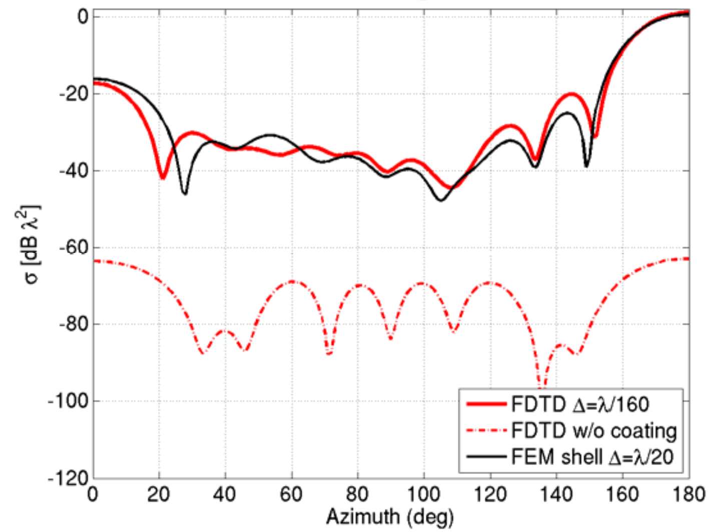
Results so far

- Development of thin sheet model
- Paper presented at EuCAP 2006 in Nice in November
- Model is currently being generalized to dispersive sheets – manuscript in preparation
- Calculated reference solutions for a magnetic dipole for comparison with the transmitting antenna (implant)



Phase of H-field in the treatment table plane





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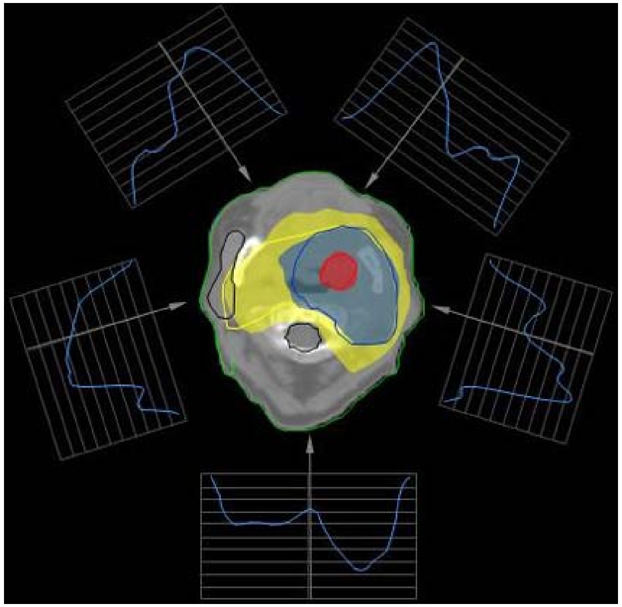
Robust IMRT plans for the biological optimisation of cancer treatment – a collaboration with SU

Goal: establish improved models and methods for the problem of finding biologically optimal radiation treatment plans in head-and-neck cancer

- Features: multi-objective problem (one goal for each target and each critical tissue); inverse problem (define constraints, find treatment parameters to meet them); for some radiation particles a forward calculation is needed



Research topics

- Access to a national database of 750 head-and-neck patients with follow-up studies of complications

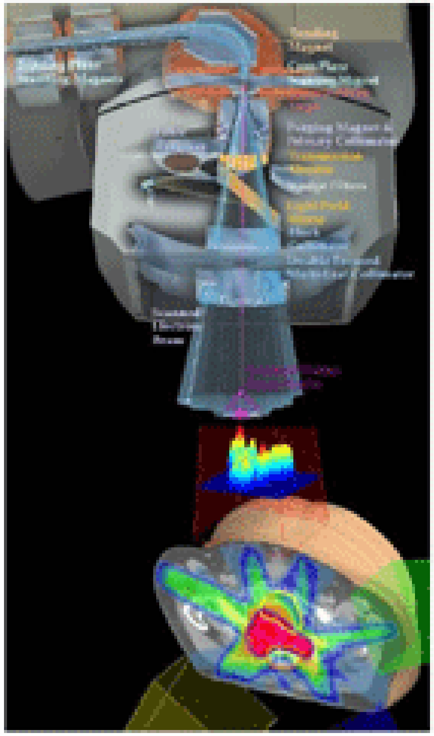
  → Improved IMRT model for cure AND complications
- Study needed of biological objective functions. (PhD student at SU sponsored by Cancerfonden)
- Improved algorithms for large-scale mixed integer problem
- Process must result in alternative treatment plans, and provide virtual plans that translate well into physical plans

Ongoing work

- Research position to be filled ASAP
- Work on a first paper on the conversion between biological and physical objectives. Important for the acceptance of a biological objective function (tumour control probability, etc.) that planners can relate to their physical view of IMRT (based on doses, DVH).
- Plan for how to use the database which will be open soon
- Gaining access to a Pareto navigator for use in the multiobjective problem with the optimisation software

Light-ion beam transport – a collaboration with KI

Goal: develop approximation models and solution techniques (FEM) for the Fermi-Eyges form of the Boltzmann equation



- This development supports treatment methods for machines with much more narrow pencil beams – an exciting future way for cancer treatment due to the higher TCP values

Future project for GMMC Optimisation – Opportunistic maintenance in industry

Goal: develop mathematical models and methods for maintenance optimisation in areas where production losses are extremely costly

- Areas: power generation (wind, nuclear, water); process industry (steel, paper); roads and infrastructure
- Common models: maintenance schedules, activities and costs (inspection, (dis)assembly costs, critical components, use of new/old spare parts), failure prediction models (monitoring, fatigue models)
- Contacts: VAC (NFFP), Vattenfall (STM), KTH (EKC^2, RCAM)