Technische Universität Graz

Workshop on

Fast Boundary Element Methods in Industrial Applications

Söllerhaus, 25.–28.9.2005

U. Langer, O. Steinbach, W. L. Wendland (eds.)

Berichte aus dem Institut für Mathematik D Numerik und Partielle Differentialgleichungen

Book of Abstracts 2005/5

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Programm

Sonntag, 25.9.2005	
15.00–16.30	Kaffee
16.30–16.35	Eröffnung
16.35–17.05	B. Carpentieri (Graz) A matrix–free two–grid preconditioner for solving boundary integral equations in electromagnetism
17.15–17.45	G. Of (Stuttgart) Boundary Element Tearing and Interconnecting Methods in Linear Elastostatics
18.30	Abendessen
Montag, 26.9.2005	
9.00–9.30	M. L. Zitzmann (München) Hierarchical Algorithms for PEEC based EMC Simulations
9.45–10.15	A. Buchau (Stuttgart) FMM based solution of non–linear magnetostatic field problems
10.30–11.00	Kaffee
11.00–11.30	C. Pechstein (Linz) Coupled FETI/BETI for nonlinear potential problems
11.45–12.15	K. Straube (Stuttgart) Approximate hierarchical Cholesky decomposition of sparse matrices arising from curl–curl equation
12.30	Mittag
15.00–15.30	Kaffee
15.30–16.00	J. Djokic (Leipzig) Efficient Update of Hierarchical Matrices assembled by ACA and HCA
16.15–16.45	U. Kähler (Chemnitz) $\mathcal{H}^2$ matrix based Wavelet Galerkin BEM
17.00–17.30	C. Fasel (Saarbrücken) Numerical solution of nonlinear parabolic inequalities with an application in ice sheet dynamics
18.30	Abendessen

Dienstag, 27.9.2005	
9.00–9.15	Z. Andjelic (Baden) Introduction to the work at ABB
9.15–9.45	J. Smajic (Baden) Dirichlet/Neumann Laplace solver for massive multimaterial conductors using BEM with ACA
9.45–10.15	M. Conry (Baden) Simulation of coupled electromagnetic–mechanical systems using an accelerated symmetric boundary element formulation
10.30–11.00	Kaffee
11.00–11.30	O. Steinbach (Graz) Alternative representations of volume integrals in boundary element methods
11.45–12.15	T. Rueberg (Graz) Coupled time–domain boundary element analysis
12.30	Mittag
13.30–18.00	Wanderung
18.30	Abendessen
Mittwoch, 28.9.2005	
9.00–9.30	D. Prätorius (Wien) Averaging Techniques for BEM
9.45–10.15	T. S. A. Ribeiro (Graz) An adaptive cell generation for elastoplastic boundary element analysis
10.30–11.00	Kaffee
11.00–11.30	R. Grzibovskis (Saarbrücken) Geometric surface evolution using clustering
11.45	Ende des Workshops

FMM based solution of non–linear magnetostatic field problems

A. Buchau, W. Hafla, W. M. Rucker
Universität Stuttgart

The solution of non–linear magnetostatic field problems is discussed in this paper. A boundary element method in combination with volume integral equations is applied. The fully dense matrix of the system of linear equations is compressed with the fast multipole method. In practice, the material values in adjacent computing domains differ by multiple orders of magnitude. A difference field approach is used to improve numerical stability and to reduce the influence of cancellation errors. Several solvers for the non–linear problem are compared. Furthermore, practical aspects of the method are discussed. The efficiency and accuracy is shown with numerical examples. E.g. the magnetic field for the Magnetic Transmission X–ray Project at BESSY II was investigated.

A matrix–free two–grid preconditioner for solving boundary integral equations in electromagnetism

B. Carpentieri

Universität Graz

In this talk we present a matrix–free iterative scheme based on the GMRES method and combined with the fast multipole method for solving electromagnetic scattering applications expressed in the popular EFIE formulation. The preconditioner is an additive two–grid cycle built on top of a sparse approximate inverse that is used as smoother. The grid transfer operators are defined in terms of spectral information of the preconditioned matrix. We show experiments on a set of linear systems arising from radar cross section calculation in industry to illustrate the potential of our method for solving large scale problems in electromagnetism.

Simulation of Coupled Electromagnetic–Mechanical Systems Using an Accelareted Symmetric Boundary Element Formulation

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[1]ABB Switzerland Ltd., [2]TU Graz

The simulation of coupled electromagnetic–mechanical systems is important in the design of commercial power–systems. Electromagnetic loading induces eddy currents in conducting components, and the resulting Lorentz forces can damage of destroy mechanical structures such as bus–bars and switches. Based on a symmetric boundary element formulation, and using ACA [1], an accelerated BEM solver for problems of linear elasticity has been implemented. Using body–force terms, this has been linked with a boundary element electromagnetic solver allowing the treatment of coupled electromagnetic–mechanical problems within a single BEM framework.

References

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Dirichlet/Neumann Laplace Solver for Massive Multimaterial Conductors using BEM with ACA

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[1]ABB Switzerland Ltd., [2]Universität Leipzig

Complete integral equation based formulation for the computation of stationary current distribution in multimaterial, multibody [1], massive conductors is proposed and compared with other classical integral formulations. An attempt to generalize the multimaterial approach to partially symmetric formulation is also provided. The approach can treat pure Neumann problems without the need for regularization. Discretization of the integral formulation is carried out via Galerkin technique. The Adaptive Cross Approximation (ACA) technique is used for matrix compression, as well as for preconditioning [2, 3]. Examples from the design/analysis process of power transformers and switchgears are provided and FEM comparisons attest the strenght of this method [1].

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[3] M. Bebendorf, S. Rjasanow: Adaptive Low–Rank Approximation of Collocation Matrices. Computing 70 (2003) 1–24.

Efficient Update of Hierarchical Matrices assembled by ACA and HCA

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$\mathcal{H}$–matrices have been used for solving various kinds of problems which require large matrices. The discretisation of an integral equation leads to a full matrix that can be approximated by an $\mathcal{H}$–matrix. The natural question that arises in the context of adaptive grid refinement is: if the discretisation becomes *locally* finer, is it possible to update an existing $\mathcal{H}$–matrix instead of constructing a new one?
The first update algorithms have been developed in the case when the interpolation scheme is used for assembling the low–rank blocks. The results we obtained have proven the efficiency of the method, and therefore we have tried to update the $\mathcal{H}$–matrices in the case when the low–rank blocks are assembled by adaptive cross approximation (ACA) or hybrid cross approximation (HCA). We shall also consider the case when the refinement of the grid is not done locally. The numerical results will demonstrate the efficiency of the update algorithm.
This is a joint work with Lars Grasedyck, Wolfgang Hackbusch and Sabine Le Borne.

Numerical solution of nonlinear parabolic inequalities with an application in ice sheet dynamics

C. Fasel
Universität des Saarlandes

Modelling the surface of an ice sheet [1,2] leads first of all to a partial differential equation with free boundary which can be transformed into a parabolic nonlinear variational inequality having the form

$$(\partial_t u, \varphi - u)_{L^2(\Omega)} + \frac{1}{5}(u^5|\partial_x u|^2 u^5, \partial_x(\varphi - u))_{L^2(\Omega)} \;\geq\; (a, \varphi - u)_{L^2(\Omega)}$$

$$\forall \varphi \in V \;:=\; \left\{\phi \in H^1(I; L^2(\Omega)) \cap L^2(I; H_0^1(\Omega)) \;\middle|\; \phi \geq 0\right\}$$

completed by the initial condition

$$u(0, x) \;=\; u_0(x).$$

This inequality is going to be solved using a finite difference method for discretisation in time, linearise it following the method of Kacanov and finally discretise using linear finite elements in space. The obtained minimizing problem on a convex set is solved by two different algorithms in order to examine their efficiency: the projected method of Gauss–Seidel and a modified method of projected gradients. Computation was based on the library DEAL [3].

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Geometric surface evolution using clustering

R. Grzibovskis
Universität des Saarlandes

We present a method of tracking a geometric surface evolution. This method is based on a hierarchical clustering procedure and allows to efficiently apply convolution-thresholding schemes when the time step is small. This is important because the evolving surface can have complicated shape and, therefore, one might need $\mathcal{O}(10^6)$ triangles to describe it. We compare the efficiency of this method to the efficiency of the procedure which is based on the Fourier transform. We also present some numerical examples involving smooth surfaces as well as surfaces with singularities.

$\mathcal{H}^2$ matrix based Wavelet Galerkin BEM

U. Kähler
TU Chemnitz

This talk is devoted to the fast solution of boundary integral equations on unstructured meshes by the Galerkin scheme. To avoid the quadratic costs of traditional discretizations with their densely populated system matrices it is necessary to use fast techniques such as hierarchical matrices, the multipole method or wavelet matrix compression, which will be the topic of the talk.

On the given, possibly unstructured, mesh we construct a wavelet basis providing vanishing moments with respect to the traces of polynomials in the space. With this basis at hand, the system matrix in wavelet coordinates can be compressed to $\mathcal{O}(N \log N)$ relevant matrix coefficients, where N denotes the number of unknowns. For the computation of the compressed system matrix with suboptimal complexity we will present a new method based on the strong similarities of substructures of the $\mathcal{H}^2$ matrices and the used wavelet basis.

Boundary Element Tearing and Interconnecting Methods in Linear Elastostatics

G. Of[1], O. Steinbach[2], W. L. Wendland[1]
[1]Universität Stuttgart, [2]TU Graz

The Boundary Element Tearing and Interconnecting (BETI) methods have recently been introduced in [1] as boundary element counterparts of the well-established Finite Element Tearing and Interconnecting (FETI) methods. As domain decomposition methods, the BETI methods are efficient parallel solvers for large scale boundary element equations.
Here, the BETI method will be used for problems in linear elastostatics. An efficient iterative solver is provided by a twofold saddle point formulation. Efficient preconditioners are used for the global system and the local boundary integral operators. Sparse approximations of the occurring boundary integral operators are realized by the use of the Fast Multipole Method.
The treatment of floating subdomains, where the kernel of the local Steklov Poincare operator has to be eliminated by a stabilization and a global projection, is more difficult than in the case of the Laplacian. Therefore, a new all–floating formulation is presented for the BETI method. This formulation unifies and simplifies the treatment of the floating and non–floating subdomains. In the numerical examples, this formulation provides a faster solution than the standard BETI formulation. The treatment of jumping coefficients and the nearly incompressible linear elasticity is of special interest.

References

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Coupled FETI/BETI for Nonlinear Potential Problems

C. Pechstein
Johannes Kepler Universität Linz

The Finite Element Tearing and Interconnecting (FETI) method has become a well–established Domain Decomposition method allowing intense parallel computing. Not long ago, its boundary element counterpart, the Boundary Element Tearing and Interconnecting (BETI) method was introduced, as well as the coupling of both methods, FETI and BETI.

We use coupled FETI/BETI methods to solve boundary value problems for nonlinear potential problems of the form $-\nabla\cdot[\nu(|\nabla u|)\nabla u] = f$. One prominent application is the nonlinear magnetostatic problem in 2D, originating from Maxwell's equations. There, due to the underlying physics, the computational domain splits into subdomains where the coefficient ν is constant (suitable for BEM), and subdomains where ν is nonlinear (treated with FEM).

Applying Newton's method to the nonlinear variational formulation, each linearized problem has the same structure as an originally linear potential problem, except for the occurrence of matrix coefficients in the nonlinear domains. In order to get a good starting value for Newton's iteration, we use a grid hierachy. For the sake of efficiency, the linear residuals of the inner iteration must be controlled, what can be done using inexact local solvers.

Averaging Techniques for BEM

D. Praetorius
TU Wien

Averaging techniques for finite element error control, occasionally called *ZZ estimators* for the gradient recovery, enjoy a high popularity in engineering because of their striking simplicity and universality: One does not even require a PDE to apply the non-expensive post-processing routines. Recently averaging techniques have been mathematically proved to be reliable and efficient for various applications of the finite element method.
In our talk we establish a class of averaging error estimators for boundary integral methods. Symm's integral equation of the first kind with a non-local single-layer integral operator serves as a model equation studied both theoretically and numerically. We introduce new error estimators which are proven to be reliable and efficient up to terms of higher order. The higher-order terms depend on the regularity of the exact solution. Numerical experiments illustrate the theoretical results and show that the [normally unknown] error is sharply estimated by the proposed estimators, i.e. error and estimators almost coincide.
The talk is based on recent joint work with C. Carstensen (HU Berlin) and S. Funken (Brunel University).

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An adaptive cell generation for elastoplastic boundary element analysis

T. S. A. Ribeiro, C. Dünser, G. Beer
TU Graz

The boundary element method (BEM) has been shown to be an alternative to the domain methods such as the finite element method (FEM) in the analysis of many physical problems. For some problems, especially the ones that contain singularities or where an infinite domain is analyzed, there is a significant gain in accuracy when using the BEM instead of the domain methods. Besides, the reduction of input data for the BEM in comparison to FEM, for instance, is very significant, especially for infinite domains. However, when dealing with plasticity analysis, not only boundary integrals but also domain integrals have to be computed. The commonly used approach to compute these integrals is to adopt internal cells. The drawback here is the requirement of domain discretization. Even though the discretization can be optimized, in a sense that the cells can be located only where plasticity will occur, the amount of input data is still larger than for a boundary–only discretization and the computational cost can be higher than necessary depending on the definition of the cells. In the current work we intend to avoid the input of the internal cells as well as the unnecessary domain evaluations by developing a procedure to automatically generate the domain discretization of the plastic zones during the analysis. The user does not need to know a priori where the plastic zone will occur in order to discretize the domain in an optimized way. The discretization will be progressively generated only on those zones where plasticity occurs, leading to a gain in efficiency, since unnecessary domain computations can be avoided. The new method has been tested on examples and the accuracy of the results is in agreement with the solution from a finite element calculation and from a calculation with the boundary element method using predefined cells.

Coupled Time–Domain Boundary Element Analysis

T. Rüberg, M. Schanz
TU Graz

The Time–Domain Boundary Element Method has found to be well suited for modeling wave propagation phenomena in large or unbounded media. Nevertheless, material discontinuities or local non-linear effects are beyond the scope of classical BEM and require special techniques. Here, we propose a (possibly hybrid) Domain Decomposition Method in order to circumvent these limitations and to obtain an efficient solution procedure at the same time.
By means of local Dirichlet–to–Neumann maps and a weak statement of the interface conditions one obtains a condensed abstract formulation describing the global problem in a variational principle without specification of the descritization method (e.g., BEM or FEM).
Whereas this methodology has been fully established for elliptic partial differential equations, we aim at transferring it to hyperbolic initial boundary value problems.

Alternative representations of volume integrals in boundary element methods

O. Steinbach
TU Graz

General volume or Newton potentials can be transformed to surface potentials when a particular solution of the associated inhomogeneous partial differential equation is known. In particular, the associated Cauchy data can be determined by applying a multilevel finite element method.
In special cases, where the volume density function itself is a solution of a certain partial differential equation, the transformation to surface potentials can be done by using integration by parts. Then, higher order derivatives are needed.
In this talk we will discuss several theoretical and practical aspects needed in this approach.

Approximate hierarchical Cholesky decomposition of sparse matrices arising from curl–curl–equation

I. Ibragimov[1], S. Rjasanow[1], K. Straube[2]
[1]Universität des Saarlandes, [2]Robert Bosch GmbH Stuttgart

Three–dimensional problems in electromagnetic field calculation can be solved with the coupling of boundary and finite element method (BEM–FEM–coupling). Fine discretisation of complex problems yields large systems of equations. The BEM part can be solved with asymptotically optimal complexity by using adaptive cross approximation (ACA). In larger problems the main cost is caused by the FEM part. Hence, we will consider the efficient solution of large sparse linear systems with a symmetric positive definite system matrix.
For computing the exact Cholesky decomposition, reordering methods essentially affect the number of non–zeros in the factorisation (fill in). The so–called hierarchical interface clustering is suitable to construct such a reordering. For higher dimensions, preconditioned iterative methods are used for solving the systems. In order to construct a preconditioner, we will apply the hierarchical interface clustering to $\mathcal{H}$–matrix techniques and investigate the computation of an approximate Cholesky decomposition. Further, we will present an approach which is also based on low–rank approximation but computes the decomposition non–recursively. This algorithm has almost linear complexity.
The construction of these hierarchical preconditioners is evaluated by means of 3D–magnetostatic problems. Its performance is compared to an incomplete factorisation algorithm, so that conclusions about the efficiency of hierarchical approaches can be given.

Hierarchical Algorithms for PEEC based EMC Simulations

M. L. Zitzmann
BMW Forschungszentrum München

High system integration densities and an increase in the operating frequencies of modern electronic systems lead to the fact that electromagnetic (EM) field based problems caused by interconnection and package structures have to be accounted for in EM modeling. The partial element equivalent circuit (PEEC) method which was developed at IBM by Dr. A. E. Ruehli in 1974 is an integral equation based approach for time and frequency domain and has proven to be very suited for combined EM field and circuit problems. PEEC models can efficiently be simulated by conventional circuit solvers such as SPICE (simulation program for integrated circuit emphasis) based on the modified nodal analysis (MNA) approach.
For accurate simulation results an adequate discretization of the conducting object leads to very large and dense PEEC system matrices. A sparsification by modern techniques enables the application of iterative solution methods. Even so the simulation of electrical systems with practical relevance will be limited by tremendous memory and time requirements.
The aim is to efficiently apply hierarchical techniques like $\mathcal{H}$–Matrices or the fast multipole method to reach linear complexity in time and memory requirements.

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Erschienene Preprints ab Nummer 2005/1

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2005/3	U. Langer G. Of O. Steinbach W. Zulehner	Inexact Fast Multipole Boundary Element Tearing and Interconnecting Methods
2005/4	U. Langer G. Of O. Steinbach W. Zulehner	Inexact Data–Sparse Boundary Element Tearing and Interconnecting Methods
2005/5	U. Langer O. Steinbach W. L. Wendland	Fast Boundary Element Methods in Industrial Applications Söllerhaus Workshop, 25.–28.9.2005, Book of Abstracts.