Technische Universität Graz

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

Berichte aus dem Institut für Numerische Mathematik

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Program

Friday, 29.9.2006	
15.00–16.30	Coffee
16.30–16.35	Opening
16.35–17.20	H. Harbrecht (Kiel) Sparse second moment analysis for potentials on stochastic domains
17.30–18.15	C. Pechstein (Linz) Coupled FETI/BETI solvers for nonlinear potential problems in unbounded domains
18.30	Dinner
Saturday, 30.9.2006	
9.00–9.45	D. Brunner (Stuttgart) Application of the fast multipole boundary element method to the analysis of sound radiation of an engine
10.00–10.45	E. Ostermann (Hannover) Sound radiation of tyres
10.45–11.30	Coffee
11.30–12.15	C. Fasel (Saarbrücken) Nonlocal electrostatics
12.30	Lunch
15.00–15.30	Coffee
15.30–16.15	J. Djokic (Leipzig) New developments of the $\mathcal{H}$–matrix technique for BEM and FEM
16.15–17.00	M. Kuhn (Jena) Simulation of optical systems based on domain decomposition ideas
17.00–18.30	Open Problem Discussion
18.30	Dinner

Sunday, 1.10.2006	
9.00–9.45	W. Weber (Erlangen) The combination of fast BEM techniques for efficient 3D crack growth analysis
10.00–10.45	A. Pereira (Graz) A dynamic multi–domain boundary element approach to model elastic, viscoelastic and poroelastic rock media
10.45–11.30	Coffee
11.30–12.15	R. Grzibovski (Saarbrücken) An interface relaxation coupling of FEM and ACA accelerated BEM for incremental metal forming
12.30	Lunch
13.30–18.00	Hiking tour
18.30	Dinner
Monday, 2.10.2006	
9.00–9.45	D. Pusch (Linz) Sparse approximations on polygonal meshes based on boundary element domain decomposition techniques
9.45–10.30	U. Kähler (Leipzig) Wavelet radiosity
10.30–11.00	Coffee
11.00–11.45	A. Buchau (Stuttgart) Post–processing and visualization in combination with integral equation methods
11.45	Closing

Application of the Fast Multipole Boundary Element Method to the Analysis of Sound Radiation of an Engine

D. Brunner, M. Junge, Matthias Fischer
Universität Stuttgart

The reduction of noise level is a major demand on products in the automotive industry. Numerical simulations of acoustic behavior help to optimize the design of the structure in an early development stage. In this work the sound radiation of a vibrating engine is simulated using a Galerkin boundary element method based on the Burton-Miller approach. The boundary element operators are herby evaluated by means of the fast multipole method, enabling a fast and efficient computation of large-scale problems up to more than 100,000 degrees of freedom. Velocity boundary conditions are applied to the surface of the engine. The resulting Neumann-problem is solved by the generalized minimal residual method (GMRES). It is accelareted by an approximate inverse preconditioner (AIP). The results demonstrate, that the proposed method is capable of simulating typical industrial applications up to the mid frequency range.

Post–processing and visualization in combination with integral equation methods

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

Integral equation methods are very advantageous for the efficient solution of even non–linear electromagnetic field problems. The surrounding space is implicitly taken into account and only surfaces of linear and volumes of non–linear matter must be modeled and discretized. Efficient matrix compression techniques like the fast multipole method significantly reduce memory requirements and computational costs of the fully dense matrix of the appropriate linear system of equations. Nevertheless, users of a field simulation tool are not only interested in the solution of a linear system of equations but they are mainly interested in a powerful post–processing and visualization of e.g. field strengths. On the other hand, a surface mesh suffices for a solution of a problem with the BEM, but on the other hand users are mostly interested in fields inside matter or in the surrounding air. Hence, in this paper it is shown and discussed, how a post–processing in combination with a BEM can be efficiently implemented. A second mesh is used to define field points, e.g. a volume mesh to compute the field for a visualization of flux tubes. Fortunately, this second mesh is independent of the mesh of the BEM. Often, the number of field points is very large along with high computational costs. But matrix compression techniques like the fast multipole method can be applied to the post–processing, too. Then, the field even in a huge number of evaluation points is computed very fast. Post–processing tools of finite element methods can be used for a visualization of the field. Here, visualization with the program Covise, which is developed at the high performance computing center in Stuttgart, is shown. Furthermore, a very simple file format is vrml, which is a standardized format for virtual reality. Hence, the results can be viewed in true 3D. It is shown that it is only a small step from a robust and fast BEM to an impressive post–processing, which is very important especially in industrial applications.

New Developments of the $\mathcal{H}$-Matrix Technique for BEM and FEM

J. Djokić

Max–Planck–Institute for Mathematics in the Sciences, Leipzig

The hierarchical matrix technique (or briefly $\mathcal{H}$-matrix technique) has been developed during the past ten years. The main property of the hierarchical matrices is their data-sparse structure (can be described by few data) and the main advantage is that $\mathcal{H}$-matrix arithmetics can be performed in almost optimal complexity $\mathcal{O}(n \log n)$ for $n \times n$ systems. The $\mathcal{H}$-matrix technique has been efficiently applied in many research fields (FEM, BEM, control theory).

In this overview talk we will present the work on the $\mathcal{H}$-matrix techniques for FEM and BEM of the Scientific Computing Group (MPI MIS). We will briefly mention the basics of the $\mathcal{H}$-matrix theory and present the key points of the recently finished and current research.

Nonlocal Electrostatics

C. Fasel[1], S. Rjasanow[1], O. Steinbach[2]
[1]Universität des Saarlandes, Saarbrücken, [2]TU Graz

In recent years, a lively interest has been focused on the determination of electrostatic potentials of biomolecules. The electrostatic field of a virus, for example, is one criterion to determine whether another biomolecule can react with the first one or not.
The goal is to model the electric field of a molecule in water. The main problem is that water is a ponderable media. The water molecules depend on each other via hydrogenbonds, which they do not want to loose. On the other side, each water molecule wants to arrange itself in a way that offers energetic advantages.
The reaction of water is nonlocal and can be described using an integral equation with a kernel containing the fundamental solution of the Yukawa-Operator $\mathcal{L}_\kappa = \Delta - \kappa^2$.
The whole model leads to an elliptic system of eight partial differential equations, four in the inside and four in the outside of the molecule, which couple via eight interface conditions. The model is completed by two radiation conditions.
We present an analytical solution for the radial symmetric case and a fundamental solution for the operator on the outside. The analytical solution is compared with the analytical solutions of some other models.

An interface relaxation coupling of FEM and ACA accelerated BEM for incremental metal forming

R. Grzibovski
Universität des Saarlandes, Saarbrücken

Coupling of Finite Element Method (FEM) and Boundary Element Method (BEM) has proven to be useful in modeling technological precesses. During some incremental metal forming procedures only a small portion of the workpiece undergoes plastic deformations, while stress values in the rest of the material are below the proportional limit. This observation suggests applying FEM to the part of the workpiece where plastic deformations occur and compute deformations of the remaining part using BEM. We use commercial solvers to handle the FEM part of the domain and our own ACA accelerated Galerkin BEM solver to compute the elastic region. That is why the Interface Relaxation Coupling method is chosen for the procedure. It allows to perform FEM and BEM computations independently and exchange the data on the interface after each coupling step. We present examples a Dirichlet-Neumann coupling procedure for a 3D test example. We also show how the coupling iteration process can be accelerated by using Aitken's method or by linearisation.

Sparse Second Moment Analysis for Potentials on Stochastic Domains

H. Harbrecht[1], R. Schneider[1], C. Schwab[2]
[1]Christian–Albrechts–Universität zu Kiel, [2]ETH Zürich

This talk is concerned with the numerical solution of Dirichlet problems in domains with random boundary perturbations. Assuming normal perturbations with small amplitude and known mean field and two-point correlation function, we derive, using a second order shape calculus, deterministic equations for the mean field and the two-point correlation function of the random solution for the Dirichlet problem in the stochastic domain.
Using a variational boundary integral equation formulation on the mean boundary and a wavelet discretization, we present and analyze an algorithm to approximate the random solution's two-point correlation function in essentially $\mathcal{O}(N)$ work and memory, where N denotes the number of unknowns required for consistent discretization of the boundary of the domain. Here "essentially" means up to powers of $\log N$.

Wavelet Radiosity

U. Kähler
Max–Planck–Institute for Mathematics in the Sciences, Leipzig

The present talk will consider the fast solution of boundary integral equations on unstructured meshes by the Galerkin scheme. It is known that the system matrix of the scheme in a wavelet basis which provides vanishing moments with respect to traces of polynomials in the space can be compressed to $\mathcal{O}(N \log N)$ relevant matrix entries, where N denotes the number of unknowns.
Nevertheless, up to now, to solve a special boundary integral equation, namely the radiosity equation, was a difficult task. For convex geometries its kernel behaves similar to the kernel of the double layer operator. However, the presence of the visibility function in the kernel provides discontinuities for a non convex geometry, which cause trouble for the most of fast methods.
In the talk we present a Wavelet Galerkin method which is able to produce for the radiosity equation on a reasonable geometry a system matrix with $\mathcal{O}(N \log^2 N)$ relevant matrix coefficients. For that, a combination of wavelet and $\mathcal{H}^2$-techniques is presented as well as the necessary compression. Numerical experiments conclude the talk and confirm the theoretical results.

Simulation of Optical Systems Based on Domain Decomposition Ideas

M. Kuhn[1], F. Wyrowski[2]
[1]LightTrans GmbH, Jena, [2]Friedrich Schiller Universität Jena

The usage of laser and LED devices in production processes as well as in consumer products has been increased throughout the last years. Often it is necessary to transform the initial light fields into user-defined distributions. For example, diffusers can be designed such that a Gaussian laser beam can be transformed into arbitrary shapes. The design of such elements requires powerful simulation methods and optimization strategies which are based on an electromagnetic representation of light.
It turns out that even state-of-the-art numerical methods cannot solve such problems at once using a rigorous electromagnetic field model based on Maxwell's equations. In this talk, we present simulation techniques which are well suited for the simulation of optical systems. These methods are based on Domain Decomposition ideas using further physical properties of the problem which is to be solved. So called "propagation operator" are chosen for each domain meeting two requirements: fast simulation and high modeling accuracy. It will be obvious, that also the Boundary Element Methods could be applied as an alternative to existing operators. Primarily, this talk will raise questions related to the application of Boundary Element Methods and Domain Decomposition Methods for the solution of advanced optical engineering problems. Some results using the optical engineering software "VirtualLab(TM)" (www.lighttrans.com) are presented.

Sound radiation of tyres

M. Maischak, E. Ostermann, E. P. Stephan
Leibniz Universität Hannover

In cooperation with Continental AG we currently model the sound radiation of tyres in three dimensions. So far we set up a model using the transient wave equation in connection with the Boundary Element Method. The corresponding retarded potentials lead maturally to sparse matrices in contrast to to the dense matrices usually associated with the BEM., but in each time step the matrix has to be stored., creating a history of matrices. The sparsity of these matrices is a result of the intersection of acoustic cones of an element with the boundary domain, such that the actual number of interacting elements is rather small. Unfortunately, the determination of this set is the basic difficulty within this method. We designed a rough approximation algorithm and performed first numerical experiments.
In another approach, we adopt the modelling of given boundary data by a random field. The idea is to combine this method with the above mentioned retarded potentials. In order to test the so called stochastic Galerkin method, we use a Dirichlet problem in 2D with BEM in space.

Coupled FETI/BETI solvers for nonlinear potential problems in unbounded domains

U. Langer[1,2], C. Pechstein[1]

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Domain decomposition (DD) methods like the rather popular finite element tearing and interconnecting (FETI) methods, dual-primal FETI (FETI–DP) methods and balanced domain decomposition by constraints (BDDC) techniques offer massively parallelizable preconditioners for boundary value problems of the standard partial differential equations like the Poisson problem or linear elasticity. The BETI method, boundary element counterpart of the FETI method can be coupled into this framework, resulting in fast solvers which benefit from the advantages of both techniques, FEM and BEM.

The condition number of the preconditioned system can be bounded by $C(1 + \log(H/h))^2$, where the constant C is independent of the mesh size h, the average subdomain parameter H and jumps in the coefficients across subdomain interfaces.

For the application of FETI/BETI methods to magnetostatic problems, two extensions are of major interest: First, one wishes to consider the equations in the entire space $\mathbb{R}^3$, together with a radiation condition. Secondly, the modelling of nonlinearities is of upmost importance. When applying the FETI/BETI solver to the linearized Newton–type problems, the coefficient field on a subdomain may involve high variation.

We suggest a preconditioner that addresses such variation much more than a straight foreward technique would do. This can be well observed in the numerical examples. Additionally, we give a short convergence analysis for the two–dimensional case, when the exterior region is included as a subdomain into the domain decomposition framework.

Literatur

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[3] U. Langer, O. Steinbach: Boundary Element Tearing and Interconnecting Methods. Computing 71 (2003) 205–228.

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A dynamic multi–domain boundary element approach to model elastic, viscoelastic and poroelastic rock media

A. Pereira, U. Eberwien, W. Moser, G. Beer
Technische Universität Graz

In many research fields in rock mechanics engineering, such as wave propagation problems, the correct representation of infinite or semi-infinite domains is of great importance. The Boundary Element Method (BEM) is well-suited for this task since it implicitly fulfils the radiation condition. Moreover, viscoelastic and poroelastic constitutive equations should be used for a better description of the rock properties. However, to model viscoelastic and poroelastic capabilities there are only fundamental solutions available in Laplace domain BEM, and no one in time domain. In addition, the interaction between multiple domains (commonly appearing in the rock mass) must not be neglected. In order to satisfy the equilibrium and compatibility at the interface of the domains, the interface forces due to each domain contribution are derived from the Duhamel integral equation. This equation is based on the convolution integral of any form of dynamic loading with respect to the unit-impulse response matrix due to a unit pure impulse of this loading. To allow for a numerical evaluation, these Duhamel integrals are approximated by means of the Convolution Quadrature Method. This technique approximates convolution integrals by a quadrature rule, whose weights can be determined exclusively by the Laplace transformed function and a linear multi-step method. In the case of the current integrals, the convolution weights are calculated from the unit-impulse response matrices. The latter are obtained using the Laplace domain BEM, applying unit impulses on the boundary and evaluating their responses at the interfaces. In this way, a boundary element formulation for domain decomposition problems in time domain using all the advantages of the Laplace domain formulation is finally achieved allowing to model elastic, viscoelastic and poroelastic media. In order to validate the accuracy and stability of the proposed technique, some problems are solved and compared to results from the literature.

Sparse Approximations on Polygonal Meshes Based on Boundary Element Domain Decomposition Techniques

U. Langer[1,2], D. Pusch[1]
[1]Johannes Kepler Universität Linz, [2]RICAM, Linz

We present new boundary element discretizations for diffusion-type equations on polyhedral meshes. Based on boundary element domain decomposition techniques we obtain an approximation which leads to large-scale sparse linear systems.
In our numerical experiments we are applying the conjugate gradient method and it turned out that using algebraic multigrid preconditioners yield an almost optimal solver.

The combination of fast BEM techniques for efficient 3D crack growth analysis

W. Weber, K. Kolk, G. Kuhn
Universität Erlangen–Nürnberg

The simulation of crack propagation denotes a challenging task for industrial applications. To perform the simulation as effectively as possible the boundary element method (BEM) in terms of the 3D Dual BEM is utilized. The evaluation of the boundary integral equations is performed in the framework of a collocation procedure. The solution of the resulting linear system of equations is the most time consuming factor. To reduce the numerical complexity different fast techniques provide a significant speed–up.
Due to the nonlinearity of crack growth an incremental procedure has to be applied. In each increment a stress analysis is needed. Based on the accurate stress field the stress intensity factors (SIFs) are calculated by an optimized local extrapolation method. Afterwards, the new crack front is determined by a reliable 3D crack growth criterion based on experimental observations. Finally, the numerical model has to be updated for the next increment.
Usually, a crack growth simulation may slightly exceed the number of 100 increments. This leads to an increasing number of degrees of freedom (dof) during the crack propagation due to the enlargement of the crack surfaces. As a result the memory requirements are also increasing. As long as the system matrix fits into the available random access memory (RAM) a fast iterative solver is applied. Otherwise, a slower Gaussian elimination has to be chosen. To handle large practical examples efficiently fast BEM techniques are utilized.
At first the classical substructure technique is used to obtain a block wise band structured system matrix. Due to wide parts of zero entries in the matrix the memory requirements as well as the numerical effort of the matrix vector product (MVP) in the framework of the iterative solver is reduced. Furthermore, by the introducing of the discontinuities of displacements and tractions on the crack surfaces one can substitude one crack surface with respect to the integration. If any three of the six discontinuities are unknown, the system of linear equations can be reduced by the unknowns of one crack surface. Finally, the adaptive cross approximation (ACA) is applied to each substructure. This leads to significantly reduced memory requirements and a fast solution of the corresponding system of linear equations.
The efficiency of the combined methods is shown on both a standard fracture mechanics specimen and a complex industrial example.

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Erschienene Preprints ab Nummer 2005/1

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2005/2	O. Steinbach	Technische Numerik. Vorlesungsskript.
2005/3	U. Langer G. Of O. Steinbach W. Zulehner	Inexact Fast Multipole Boundary Element Tearing and Interconnecting Methods
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