A Gentle Introduction to the Boundary Element Method in Matlab/Freemat

Stephen Kirkup[1] and Javad Yazdani[1]

Abstract—The Boundary Element Method is developed in its most simple form; for the solution of Laplace's equation in an interior domain with a straight line approximation to the boundary. The direct and indirect approaches to the boundary element method are included. The methods are developed in Freemat, a language similar to Matlab.

The codes for the solution of Laplace's equation in a general domain with a general (Robin) boundary condition are developed. The codes are applied to a typical test problem. The codes are made available as open source (BEMLAP-MAT package) and can be downloaded from this paper or from the websites listed below[2]. The overall package is expected to become a teaching aid in the MSc course[3] that is presently being developed by the authors.

I. INTRODUCTION

The boundary element method (BEM) is an important computational analysis technique that engineers and scientists can apply to a range of problems There are a number of textbooks on the BEM[1-2]. The purpose of this article and the accompanying software is to meet the needs of scientists and engineers who are somewhat unfamiliar with the BEM, but have an understanding of numerical methods and computer programming, or would like to apply the BEM to appropriate engineering problems with minimal fuss.

The application of the boundary element method to an appropriate scientific or engineering problem essentially requires a mesh of the boundary of the domain only, and the determination of the boundary condition on the surface. The computational solution then yields the approximate solution at selected points in the domain.

The BEM is generally more efficient to apply and execute than competing methods, such as the finite element or finite difference methods. Hence the application of the BEM presents an attractive option to scientists and engineers. The authors are developing an MSc and this package is expected to act as a teaching aid on one of the modules in that course

On the other hand the underlying mathematical derivation and numerical analysis is extremely involved. Unfortunately, most textbooks on the BEM concentrate on the mathematics underlying the BEM, considering the ranges of integral equation formulation, ranges of element types, ranges of method derivation. In this article the elegance of the solution method is not lost in a mass of mathematical derivation and analysis. A simple notation is used to assist in the understanding of the development of the BEM.

In this work, the so-called *direct* and *indirect* boundary element methods for the solution of the interior Laplace equation are developed. Laplace's equation is the most straightforward problem to which the BEM can be applied. Laplace's equation also models a number of physical phenomena, such as steady state heat conduction and electrostatics. There is substantial recent research on the application of the BEM to Laplace's equation[3-10].

Over recent decades, Matlab[11] has become an increasingly important language for scientific computation. Freemat[12] is a freely available alternative compiler for Matlab. All codes are developed in Freemat, but they can be also used in the Matlab environment. Matlab/Freemat is based on Matrix arithmetic, allowing an economy of coding and naturally allows parallel processing, if it is available.

II. THE BOUNDARY ELEMENT METHOD

Over recent decades, the boundary element method (BEM) has received much attention from researchers and has become an important technique in the computational solution of a number of physical

[1]School of Science and Technology, East Lancashire Institute of Higher Education, Blackburn College UK.
[2] www.east-lancashire-research.org.uk
[3]www.kirkup.info/opensource
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Numerical Modeling and Computer Simulation Dragan Cvetković,Gunvant Birajdar,2020-05-06 Information technologies have changed people s lives to a great extent and now it is almost impossible to imagine any activity that does not depend on computers in some way Since the invention of first computer systems people have been trying to avail computers in order to solve complex problems in various areas Traditional methods of calculation have been replaced by computer programs that have the ability to predict the behavior of structures under different loading conditions There are eight chapters in this book that deal with optimal control of thermal pollution emitted by power plants finite difference solution of conjugate heat transfer in double pipe with trapezoidal fins photovoltaic system integrated into the buildings possibilities of modeling Petri nets and their extensions etc **Introduction to Finite and Spectral Element Methods Using MATLAB** Constantine Pozrikidis,2014-06-20 Incorporating new topics and original material Introduction to Finite and Spectral Element Methods Using MATLAB Second Edition enables readers to quickly understand the theoretical foundation and practical implementation of the finite element method and its companion spectral element method Readers gain hands on computational experience by using *The Finite Element Method* Darrell W. Pepper,Juan C. Heinrich,2017-04-11 This self explanatory guide introduces the basic fundamentals of the Finite Element Method in a clear manner using comprehensive examples Beginning with the concept of one dimensional heat transfer the first chapters include one dimensional problems that can be solved by inspection The book progresses through more detailed two dimensional elements to three dimensional elements including discussions on various applications and ending with introductory chapters on the boundary element and meshless methods where more input data must be provided to solve problems Emphasis is placed on the development of the discrete set of algebraic equations The example problems and exercises in each chapter explain the procedure for defining and organizing the required initial and boundary condition data for a specific problem and computer code listings in MATLAB and MAPLE are included for setting up the examples within the text including COMSOL files Widely used as an introductory Finite Element Method text since 1992 and used in past ASME short courses and AIAA home study courses this text is intended for undergraduate and graduate students taking Finite Element Methodology courses engineers working in the industry that need to become familiar with the FEM and engineers working in the field of heat transfer It can also be used for distance education courses that can be conducted on the web Highlights of the new edition include Inclusion of MATLAB MAPLE code listings along with several COMSOL files for the example problems within the text Power point presentations per chapter and a solution manual are also available from the web Additional introductory chapters on the boundary element method and the meshless method Revised and updated content Simple and easy to follow guidelines for understanding and applying the Finite Element Method **The Boundary Element Method for Engineers and Scientists** John T. Katsikadelis,2016-10-10 The Boundary Element Method for Engineers and Scientists Theory and

Applications is a detailed introduction to the principles and use of boundary element method BEM enabling this versatile and powerful computational tool to be employed for engineering analysis and design In this book Dr Katsikadelis presents the underlying principles and explains how the BEM equations are formed and numerically solved using only the mathematics and mechanics to which readers will have been exposed during undergraduate studies All concepts are illustrated with worked examples and problems helping to put theory into practice and to familiarize the reader with BEM programming through the use of code and programs listed in the book and also available in electronic form on the book s companion website Offers an accessible guide to BEM principles and numerical implementation with worked examples and detailed discussion of practical applications This second edition features three new chapters including coverage of the dual reciprocity method DRM and analog equation method AEM with their application to complicated problems including time dependent and non linear problems as well as problems described by fractional differential equations Companion website includes source code of all computer programs developed in the book for the solution of a broad range of real life engineering problems   **The Finite Element Method** Darrell W. Pepper,Juan C. Heinrich,2017 This self explanatory guide introduces the basic fundamentals of the Finite Element Method in a clear manner using comprehensive examples Beginning with the concept of one dimensional heat transfer the first chapters include one dimensional problems that can be solved by inspection The book progresses through more detailed two dimensional elements to three dimensional elements including discussions on various applications and ending with introductory chapters on the boundary element and meshless methods where more input data must be provided to solve problems Emphasis is placed on the development of the discrete set of algebraic equations The example problems and exercises in each chapter explain the procedure for defining and organizing the required initial and boundary condition data for a specific problem and computer code listings in MATLAB and MAPLE are included for setting up the examples within the text including COMSOL files   Rock Mechanics and Engineering Volume 1 Xia-Ting Feng,2017-03-16 Principles is the first volume of the five volume set Rock Mechanics and Engineering and contains twenty four chapters from key experts in the following fields Discontinuities Anisotropy Rock Stress Geophysics Strength Criteria Modeling Rock Deformation and Failure The five volume set Comprehensive Rock Engineering which was published in 1993 has had an important influence on the development of rock mechanics and rock engineering Significant and extensive advances and achievements in these fields over the last 20 years now justify the publishing of a comparable new compilation Rock Mechanics and Engineering represents a highly prestigious multi volume work edited by Professor Xia Ting Feng with the editorial advice of Professor John A Hudson This new compilation offers an extremely wideranging and comprehensive overview of the state of the art in rock mechanics and rock engineering and is composed of peer reviewed dedicated contributions by all the key experts worldwide Key features of this set are that it provides a systematic global summary of new developments in rock mechanics and rock engineering practices as well as looking ahead to future

developments in the fields Contributors are worldrenowned experts in the fields of rock mechanics and rock engineering though younger talented researchers have also been included The individual volumes cover an extremely wide array of topics grouped under five overarching themes Principles Vol 1 Laboratory and Field Testing Vol 2 Analysis Modelling and Design Vol 3 Excavation Support and Monitoring Vol 4 and Surface and Underground Projects Vol 5 This multi volume work sets a new standard for rock mechanics and engineering compendia and will be the go to resource for all engineering professionals and academics involved in rock mechanics and engineering for years to come   Harmonising Rock Engineering and the Environment Qihu Qian,Yingxin Zhou,2011-09-14 Harmonising Rock Mechanics and the Environment comprises the proceedings invited and contributed papers of the 12th ISRM International Congress on Rock Mechanics Beijing China 18 21 October 2011 The contributions cover the entire scope of rock mechanics and rock engineering with an emphasis on the critical role of both disciplines in sustai   *Simulation of Electrochemical Processes II* V.G. DeGiorgi,C.A. Brebbia,R.A. Adey,2007-04-10 This book contains papers presented at the Second International Conference in this successful series which presents and discusses the state of the art on the computer simulation of corrosion electrochemical processes and the electrical and electromagnetic fields associated with them Modern industry applies a wide range of electrochemical processes to protect against corrosion provide surface treatments and to manufacture products This book focuses on the computer modelling of these industrial processes and techniques by examining the developments of computational models and their application in practice Featured topics include Cathodic Protection Systems Modelling Methodologies Electrodeposition and Electroforming Modelling of Coatings Modelling Stress Corrosion Cracking and Corrosion Fatigue Modelling and Corrosion of Surface Coatings Interference and Signature Control Anodic Protection Electrocoating and Plating Optimisation of Control Systems Detection and Monitoring of Corrosion Measurement Techniques Fuel on Photovoltaic Cells Electrolysis Reactors Comparison of Experimental Measurements and Computer results Case Studies

    Numerical Sound Synthesis Stefan Bilbao,2009-09-03 Digital sound synthesis has long been approached using standard digital filtering techniques Newer synthesis strategies however make use of physical descriptions of musical instruments and allow for much more realistic and complex sound production and thereby synthesis becomes a problem of simulation This book has a special focus on time domain finite difference methods presented within an audio framework It covers time series and difference operators and basic tools for the construction and analysis of finite difference schemes including frequency domain and energy based methods with special attention paid to problems inherent to sound synthesis Various basic lumped systems and excitation mechanisms are covered followed by a look at the 1D wave equation linear bar and string vibration acoustic tube modelling and linear membrane and plate vibration Various advanced topics such as the nonlinear vibration of strings and plates are given an elaborate treatment Key features Includes a historical overview of digital sound synthesis techniques highlighting the links between the various physical modelling methodologies A pedagogical presentation

containing over 150 problems and programming exercises and numerous figures and diagrams and code fragments in the MATLAB programming language helps the reader with limited experience of numerical methods reach an understanding of this subject Offers a complete treatment of all of the major families of musical instruments including certain audio effects Numerical Sound Synthesis is suitable for audio and software engineers and researchers in digital audio sound synthesis and more general musical acoustics Graduate students in electrical engineering mechanical engineering or computer science working on the more technical side of digital audio and sound synthesis will also find this book of interest *Stanford Bulletin* ,2006 <u>Microelectromechanical Systems</u> ,1996 <u>Symmetric Galerkin Boundary Element Method</u> Alok Sutradhar,Glaucio Paulino,Leonard J. Gray,2008-09-26 Symmetric Galerkin Boundary Element Method presents an introduction as well as recent developments of this accurate powerful and versatile method The formulation possesses the attractive feature of producing a symmetric coefficient matrix In addition the Galerkin approximation allows standard continuous elements to be used for evaluation of hypersingular integrals FEATURES Written in a form suitable for a graduate level textbook as well as a self learning tutorial in the field Covers applications in two dimensional and three dimensional problems of potential theory and elasticity Additional basic topics involve axisymmetry multi zone and interface formulations More advanced topics include fluid flow wave breaking over a sloping beach non homogeneous media functionally graded materials FGMs anisotropic elasticity error estimation adaptivity and fracture mechanics Presents integral equations as a basis for the formulation of general symmetric Galerkin boundary element methods and their corresponding numerical implementation Designed to convey effective unified procedures for the treatment of singular and hypersingular integrals that naturally arise in the method Symbolic codes using Maple for singular type integrations are provided and discussed in detail The user friendly adaptive computer code BEAN Boundary Element ANalysis fully written in Matlab is available as a companion to the text The complete source code including the graphical user interface GUI can be downloaded from the web site http www ghpaulino com SGBEM_book The source code can be used as the basis for building new applications and should also function as an effective teaching tool To facilitate the use of BEAN a video tutorial and a library of practical examples are provided *Solid-State Sensor and Actuator Workshop, Hilton Head Island, South Carolina, June 3-6, 1996* ,1996 **The Scaled Boundary Finite Element Method** Chongmin Song,2018-06-19 An informative look at the theory computer implementation and application of the scaled boundary finite element method This reliable resource complete with MATLAB is an easy to understand introduction to the fundamental principles of the scaled boundary finite element method It establishes the theory of the scaled boundary finite element method systematically as a general numerical procedure providing the reader with a sound knowledge to expand the applications of this method to a broader scope The book also presents the applications of the scaled boundary finite element to illustrate its salient features and potentials The Scaled Boundary Finite Element Method Introduction to Theory and Implementation covers the static and dynamic stress analysis of

solids in two and three dimensions The relevant concepts theory and modelling issues of the scaled boundary finite element method are discussed and the unique features of the method are highlighted The applications in computational fracture mechanics are detailed with numerical examples A unified mesh generation procedure based on quadtree octree algorithm is described It also presents examples of fully automatic stress analysis of geometric models in NURBS STL and digital images Written in lucid and easy to understand language by the co inventor of the scaled boundary element method Provides MATLAB as an integral part of the book with the code cross referenced in the text and the use of the code illustrated by examples Presents new developments in the scaled boundary finite element method with illustrative examples so that readers can appreciate the significant features and potentials of this novel method especially in emerging technologies such as 3D printing virtual reality and digital image based analysis The Scaled Boundary Finite Element Method Introduction to Theory and Implementation is an ideal book for researchers software developers numerical analysts and postgraduate students in many fields of engineering and science **Theory and Numerics of Ordinary and Partial Differential Equations** M. Ainsworth,1995 This book surveys the most recent research in six key areas related to numerical solutions of differential equations It covers guaranteed error bounds for ordinary differential equations an introduction to computational methods for differential equations numerical solution of differential algebraic equations boundary element methods and perturbation theory for infinite dimensional dynamical systems It draws together a method that is currently only available in journals introducing the reader to important current research This book is written at a level for graduate students and researchers in computational mathematics and in application areas in physics and engineering A Practical Guide to Boundary Element Methods with the Software Library BEMLIB C. Pozrikidis,2002-05-15 The boundary element method is a powerful numerical technique for solving partial differential equations encountered in applied mathematics science and engineering The strength of the method derives from its ability to solve with notable efficiency problems in domains with complex and possibly evolving geometry where traditional methods can be demanding cumbersome or unreliable This dual purpose text provides a concise introduction to the theory and implementation of boundary element methods while simultaneously offering hands on experience based on the software library BEMLIB BEMLIB contains four directories comprising a collection of FORTRAN 77 programs and codes on Green s functions and boundary element methods for Laplace Helmholtz and Stokes flow problems The software is freely available from the Internet site http bemlib ucsd edu The first seven chapters of the text discuss the theoretical foundation and practical implementation of the boundary element method The material includes both classical topics and recent developments such as methods for solving inhomogeneous nonlinear and time dependent equations The last five chapters comprise the BEMLIB user guide which discusses the mathematical formulation of the problems considered outlines the numerical methods and describes the structure of the boundary element codes A Practical Guide to Boundary Element Methods with the Software Library BEMLIB is ideal for self study and as a text for an introductory course on

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