TEACHING NUMERICAL METHODS OF SOLVING TECHNICAL PROBLEMS

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Abstract: *The philosophy of a subject implemented into the curricula of the new Faculty of Electrical Engineering and Communication, Brno University of Technology, is given in the paper. The aim of the subject is to offer (not only) a mathematical basis of truly effective utilization of computer supported solutions of technical problems.*

Introduction

Presently, computer aided solutions of technical problems take place particularly in the following areas:

1. Utilization of special software tools. For the Electrical Engineering applications, the typical representatives are circuit simulators.
2. Utilization of universal programs for scientific computations, such as MATLAB+SIMULINK, MATHCAD, MAPLE, MATHEMATICA, etc.
3. Utilization of a high-level language.

In all the cases, the procedures (which may be formally different) can be summarized as follows: A physical phenomenon is expressed by a mathematical model, which is evaluated subsequently by means of numerical or symbolic methods. Working in area 1, the user –if no problem appears – need not be interested deeply in these methods. But in area 2, he solves the problem of how to choose embedded algorithms, and in area 3 he will probably develop his own algorithms.

It would seem at first sight that solving a complicated numerical task in C++ would require an in-depth mastering of numerical methods, but that it is not necessary for working with the SPICE simulator. However, everyday experience in simulator software indicates a serious problem: The user often loses control over the program because he is not its builder, and therefore he does not understand the basic mechanism of its operation. Also, if he is not able to predict a real simulation result, then he will accept simulator outputs even if they are in conflict with the reality (e.g. due to improper global or local simulator settings). The student is often confused if the simulator is unable to find the solution in a given number of iterations, and he changes randomly the settings of various items until “some” solution is found. Nevertheless, it would be sufficient to know the parameters of embedded iteration methods, error criteria and the corresponding simulator global settings. A sad situations arises if the program offers the choice of embedded method of solution (e.g. method of integration), and the user – due to ignorance – will leave unchanged the implicit setting, with all the possible negative consequences.

Indeed, mastering the standard numerical methods is unavoidable when working in areas 2 or even 3.

The reality described above led to the origin of the subject about (not only) numerical methods, lectured by the teachers in technical departments (not mathematicians).

Characterization of the subject „Computer supported solution of technical problems“

The conception of the subject „ Computer-supported solution of technical problems “ reflects the above reality and offers a technical and user’s interpretation of the numerical methods used in popular CAD programs and in programs for scientific computation. The individual methods are evaluated in the light of their numerical stability, computational speed and accuracy. Conclusions are given as to their practical applicability to solving concrete types of technical problems on concrete hardware.

Inside a given group, the methods are classified according to their features and practical applicability. The reading is then focused on the methods that have been well-tested by practice. For these methods, the source codes in MATLAB (and Fortran, Pascal, and C) for computer exercise are available.

The outline enclosed is written for the “Communication and informatics” field of study, and it includes widespread methods of solving both the linear and nonlinear problems. The individual algorithms are classified in modular units, which can be modified for different branches of study (e.g. the methods of Fourier transforms and generalized spectral analysis can be included in the “signal processing” branches, the sorting and searching algorithms for “informatics”, etc.).

The content of the subject is based on two well-known monographs [1] and [2], and on the long-time research activities at the Faculty of EE and Informatics in the area of computer simulation of electrical systems.

Conclusion

The subject described will be included in the teaching process after finishing the current curricula. That is why no pedagogical experience or feedback is available at this time. However, we can hope that the main aim will be fulfilled, i.e. creating a firm base for qualified utilization of modern software tools for solving technical problems.

Acknowledgement

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References

[1] PRESS,W.H. et al.: Numerical Recipes in Pascal. The Art of Scientific Computing. Cambridge University Press, 1994. ISBN 0-521-37516-9 (book), 0-521-37532-0 (CD).

[2] ACTON, F.S.: Numerical Methods that Work. The Mathematical Association of America, Washington D.C., 1990. ISBN 0-88385-450-3.

Appendix: Detailed subject outline

Numerical methods of solving technical problems
with a view to Electronics and Communications

Introduction to the computer solution of technical problems.
Modelling, analysis, simulation. Problem definition, compilation of mathematical model, choice of the numerical method, choice of an adequate software tool, method implementation. Typical examples from the technical practice.

Basics of numerical and symbolic methods.
Principle of the numerical and symbolic methods. Universal and special software tools for scientific calculations. Numerical errors, ill-conditioned problems. Examples from the technical practice. Strategy and tactics in model compilation, choice of the method, and its implementation. List of groups of numerical methods for the solution of frequent technical problems.

Algorithms for solving linear problems.

Finding DC steady states in linear electrical circuits, algorithms of computing AC relations and frequency responses of linear circuits. Other problems which lead to the solution of the set of linear real or complex equations.

Algorithmic solution of a set of linear equations. The Gauss-Jordan elimination with partial and full pivoting. LU decomposition. Methods of matrix inversion and determinant computation. Iterative root polishing.

The SVD (Singular Value Decomposition) algorithm and its „least-square“ applications in Electrical Engineering.

Sparse linear systems and sparse matrices. Fundamentals of the algorithms for effective solution of large linear systems.

Semisymbolic analysis of systems in the operator domain. Stability testing of linear systems. Other problems leading to finding the eigenvalues of system matrices or finding the roots of characteristic equations.

Deflation algorithms of system matrices. Finding the zeros and poles of linear systems via the eigenvalues of system matrices. Algorithms for the standard and generalized eigenvalue problems. The QR, QL, and QZ algorithms. System matrix balancing and its reduction to the Hessenberg form. Results improvements via inverse iterations. Application – algorithmic computing of zeros/poles of large systems. Well-tried EISPACK, CIA and SNAP algorithms.

Other algorithms of semisymbolic analysis of linear systems: approximation method which utilizes the FFT algorithm, Faddejev algorithm.

Algorithms for finding roots of the characteristic polynomials of linear systems. The problem of multiple roots and ill-conditioned polynomials. Polynomial deflation. The Muller method. The Laguerr method. The method that uses the associated system matrix. Procedures of the primary and secondary root polishing. Well-tried EISPACK and SNAP algorithms.

Symbolic system analysis in the operator domain.

The substance and the aims of symbolic analysis. The algebraic and topological methods. Simplifications of the symbolic results. The SAG, SBG, and SDG methods. Algorithms from the COCO, COFACTOR, and SNAP programs. Utilization of the MAPLE and MATHEMATICA programs for symbolic computations.

Semisymbolic and numerical system analysis in the time domain.

Computation of the time system response from the operator model – system function, operator state equation, or the set of operator equations. Computation of the forced response. Methods of finding the periodical steady state. Methods of numerical inversion of the Laplace transform – the Zakian, Vlach-Singhal, Valsa methods. The semisymbolic Laplace inversion of rational fraction system function. Algorithms of partial fraction expansion.

Algorithms for solving nonlinear problems.

Finding the DC operating points of electronic systems. Other problems leading to finding the solution of a set of nonlinear algebraic equations.

The main problems in the area of iterative methods. The survey of iterative methods. The Newton-Raphson method. The convergence problems. The convergence criteria. The STOP criteria. Characterization of numerical algorithms for finding DC operating points in professional circuit simulators (SPICE, MicroCap, El. Workbench and others). The significance of global settings from the viewpoint of convergence criteria.

Transient analysis of electronic systems. Other problems leading to finding the solution of a set of nonlinear differential equations.

The main problems in the area of methods for the solution of nonlinear differential equations. The Runge-Kutta method with the fixed and the variable step. The Richardson extrapolation and the Bulirsch-Stoer method. The predictor-corrector methods. The problem of „stiff“ systems simulation. The characterization of algorithms of transient analysis in the professional SPICE-family simulators. The significance of global settings from the viewpoint of the operation of predictor-corrector methods.

Approximation of function dependences in nonlinear systems. System identification. Curve fittings. Other problems leading to the mathematical operations of approximation, interpolation, or extrapolation.

Basic conception. The polynomial and rational fraction interpolation and extrapolation. The cubic splines. The LMS approach. The linear LMS method – classical solution and SVD-based solution. Nonlinear methods. The Levenberg-Marquardth method.

Statistical analysis of electronic systems. Other problems leading to the software generation of random numbers, their transformation by a system, and the subsequent statistical evaluation of consequences.

The Monte Carlo and the Worst Case methods. Generators of random numbers – linear, exponential, normal probability distributions. Generators of random binary symbols. Methods of statistical data processing in circuit simulators. Objective functions.