Interval Computations
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REVIEW

of the Book: Ludyk, G. *"CAE von Dynamischen Systemen. Analyse. Simulation, Entwurf von Regelungssystem".* — Springer-Verlag, Berlin-Heidelberg, 1990 — 335 p.

In this book, some topics of applied mathematics widely used in control system theory are outlined in a new way. The novelty consists of 1) consideration of computational algorithms from the interval mathematics point of view, 2) expanding known methods to plants with interval uncertainty, 3) describing special new computational methods that account for intervals.

The book consists of 9 chapters and appendix.

In the chapter "Basics of the computer arithmetics", information on computer numbers, rounding errors and directed roundings, special features of "interval" PASCAL and FORTRAN versions are outlined, concepts of the condition of the problem and the quality of algorithms for its solution are introduced.

Chapter 2 "Eigenvalues and eigenvectors" contains a description of methods and appropriate algorithms for computing eigenvalues of matrices with the characteristic equation and with an orthogonal similarity transformation. The roots of polynomials of second and third degrees are determined with rational operations; for high-degree polynomials, the relationship with a companion matrix is used. The matrix methods involve generalized and real Schur forms, QR expansions by means of Householder and Hessenberg forms using Givens and Francis matrices. An example of an ill-conditioned problem — finding roots of 20th order polynomial (Wilkinson) and a technical example — description of a constant current engine with interval coefficients are given.

Chapter 3 "High accuracy solution of systems of equations" contains sections on the following: (i) the formulation of a problem based on the example of Newton's method, (ii) interval methods for solving systems of linear and non-linear equations, (iii) systems of linear interval equations, (iv) high accuracy determination of an inverse matrix, (v) applications of the methods to the eigenvalue (real and complex) problem.

Chapter 4 "Controllability and assignment of poles" is devoted to the most important questions of the control theory. Here, along with determination of controllability of discrete and continuous dynamical systems, much attention is given to the structural singularities of the controllability matrix for the case of scalar and multivariate systems. In this case, the Hessenberg form described in chapter 2 is used. The fundamental question of introduction of feedback into a dynamical system is solved with modal control methods. For systems with single input and single output, the numerical determination of the feedback vectors is performed in two ways: by means of the Ackermann forms (in three modifications, and in one of them the interval controllability matrix is used) and by reducing the plant to the Hessenberg form (Minimis and Paige have proposed). For multiply connected systems four methods of solving this problem are described.

In chapter 5 "Observability and renewal of states", definitions of dual problems to the problems in chapter 4 are given and an observer arrangement is described conceptually.

Chapter 6 "Decomposition with respect to singular values and applications" is devoted to very important mathematical characteristics of the automated system — to singular values of matrices of its model. First the singular values are linked with geometrical notions of matrix theory (range, core) then the method of their computation proposed by Golub and Reinsch and also a high accuracy computational method are described. Along with this, much attention is given to applications of the singular values which can be used for decomposition of the system into the controllable, non-controllable, observable, and non-observable subsystems, for the explanation of geometrical theory of the perturbation relaxation, for the transformation of the plant model to a special form and the subsequent reduction of its order, in the lest-squares method and the pseudo-inversion of matrices.

Chapter 7 "Modelling dynamical systems" is of the most interest because of the novelty of its material. In the first subsection classical methods of the integration of ordinary differential equations are investigated. Using Euler's method as an example, the process of the integration and its dependence on the discretization step are shown, the error of the method is linked to the Taylor series in terms of the concept of its locality, globality, etc. Then the Runge-Kutta method, techniques of the error correction and stepsize control are analyzed. Excellent examples of differential equations with the strict dependence of the initial conditions and the step (strict differential equations) conclude this subsection. The second subsection is devoted to the state equations. The concepts of the transition matrix and its properties, the principle of modelling with this matrix and three methods of computing it (diagonalization, representation as a series, and Pade approximation) are discussed. The description of current results is concentrated in the third subsection "Modelling systems with initial conditions and parameters as intervals." Three types of the problems are formulated: 1) computation of a good interval estimate for the solution of the differential equations with exactly known (normal, as the author calls them) initial conditions, 2) the same but with an interval vector of the initial conditions, 3) the same but with the differential equations parameters as intervals. The difficulty of solving these problems is demonstrated on the example of the "wrapping effect". A statement on the reduction of problem (3) to problem (2) is also interesting. However, in this case the linear differential equations are transformed into non-linear ones and the dimension of the state vector increases. The subsequent development follows along the lines of papers of Lohner, the central ideas of which are the recursive computation of expansion coefficients in the Taylor series of elementary functions, linearization, and matrix methods of prediction of the global error. Unfortunately, no algorithms for this material are provided.

The material of chapters 8 and 9 ("The Lyapunov and Riccati equations" and "Frequency characteristics", respectively) emphasizes the emphasis of the book on automatic control theory. In chapter 8 the relationship of the basic conditions of regulated system efficiency — stability and quality — with the Lyapunov and Riccati equations in the continuous and the discrete matrix forms is considered. Algorithms of the numerical solution methods for these equations are given. In chapter 9 an interesting algorithm for construction of the frequency characteristics is described.

This algorithm is constructed directly from the matrix description of the plant in a state space. The implementation of the algorithm in PASCAL-XSC provides a possibility to obtain regions of location of the frequency characteristics for systems with interval parameters.

In the Appendix there is some necessary elementary information on interval computations: interval arithmetic, its computer implementation, interval representation of functions, interval matrices and vectors.

As a whole the book makes a favorable impression, not only because of the consideration of the computational questions, but also because of the applications of interval methods to plants with interval uncertainty and numerous thoroughly selected examples and well thought-out algorithms. The material on the analysis of controllability — observability, frequency characteristics, and modelling of the interval automatic systems is very useful.

Also there are some shortcomings. The most substantial one is ignoring of the results published in the international journals on the automatic control theory (Automatica, International Journal of Control, IEEE Transations on Automatic Control, etc.) in the period from 1978 to 1988, results that are directly relevant to the theme of the book. However, these results concern both mathematical questions (for example, the fundamental result of V.L.Kharitonov on interval polynomials, the papers on the stability of interval matrices) and the special questions of the robust theory of the automatic control (interval modal control, interval Riccati equation, robust frequency methods, papers on "roughness" of observes). If the author included these materials in the chapters 5,8,9, the book would be free of the second shortcoming: the striking non-balancing of the chapter sizes. For example, chapters 2,4 and 6 occupy about 60 pages each, while chapters 8,9 occupy 15 pages each, although the themes of these later chapters are carried in the subhead-line of the book.

There are also small shortcomings. For example, numbering of algorithms is not in order but with skips. Next, in algorithms 4.10 (p.108) there is a reference on the missing algorithm 2.16 and the reference on formula 7.190 (p.275) gives rise to doubt.

However, anyone who has read this monograph, be they a specialist on control theory or computational mathematics, will feel true pleasure from the methodical, careful, and , and extensive nature of the outlined material. The book will doubtless be useful, to instructors offering special courses on the computational aspects of automatic control theory.

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Editor's note. Although the reviewed book was published in 1990 and some special aspects of it have already became obsolete, we decided to place this review in our journal, since it seemed is not yet widely enough known among specialists in interval computations.