Detection of Abrupt Changes: Theory and Application

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The problem of change detection/diagnosis in signals and systems has received considerable attention during the last two decades in a research context and appears to be at the heart of various application domains such as: speech processing, image processing, automatic analysis of biomedical signals, signal processing in cars, digital data transmission systems, underwater acoustics, geophysics, failure detection in controlled systems (aeronautics, chemical and nuclear processes, event- detection of incident on freeways), econometrics, etc.

Detection of Abrupt Changes: Theory and Application is the first book to present the newest mathematical tools and techniques for solving change detection problems in a wide domain like that presented above. It covers a large class of stochastic processes, from scalar independent observations to multidimensional dependent ARMA and state-space models, the properties of the algorithms for statistical change detection, tuning and optimizing change detection algorithms, and real-world applications.

The problems of change detection/diagnosis result from an increasing complexity of most of the technological processes, the availability of sophisticated sensors in both technological and natural worlds, and the existence of sophisticated information processing systems, which are widely used.

The problems that constitute the subject of the book share the feature that the element of interest is in the detection of one or several abrupt changes in some characteristic properties of the object considered. The key difficulty lies in the detection of intrinsic changes that are not necessarily observed directly and of which measurement is done together with other types of perturbations. The main goal of this book is to describe a unified framework for the design and the performance analysis of the algorithms for solving these change detection problems. The book is basically devoted to the design and investigation of on-line change detection algorithms. The off-line problem statement is discussed more briefly, mainly with a view at highlighting some applications. The authors mainly focus on parametric statistical tools for detecting abrupt changes in properties of discrete -time signals and dynamic systems. They present didactically generalizations of points of view for designing algorithms together with new results, both theoretical and experimental. The starting point is elementary well-known detectors, used in industrial applications, and then generalized in more complex situations in which spectral properties of signals or dynamic properties of systems do change.

The book is intended to be a bridge between mathematical statistics tools and applied problems. First the reader is introduced to the basic ideas using a nonformal presentation in the simplest case. Then the authors include the key mathematical background necessary for the design and performance evaluation of change detection algorithms. The book is full of interesting ideas and advanced concepts which make it present attractiveness for graduate students, theorists, practitioners and researchers involved in signal processing, automatic control and supervision, time series analysis, applied statistics, quality control, and preventive maintenance and monitoring of plants.

The book is structured in eleven Chapters. The first five chapters constitute Part I, devoted to algorithms for change detection in the scalar parameter of an independent sequence of observations. Part II, including the next four Chapters, is concerned with the extension of these algorithms to more complex situations of changes in the vector parameter of an independent sequence, additive changes in a possibly dependent sequence, and non-additive changes in a dependent sequence too. Part III, the last two chapters, is devoted to tuning and application issues.

Chapter 1 represents the introductory chapter of the book that defines the change detection problem with application examples. It presents the content of the book and some further critical issues.

Chapter 2 introduces the reader to the theory of on-line detection algorithms in the framework of an independent random sequence parameterized by a scalar parameter. The following topics, for known parameters before and after change, are discussed: elementary algorithms of common use in industrial applications (Shewhart control charts, finite or infinite moving average control charts, and filtered derivative algorithms), the CUSUM algorithm, from on-line and off-line points of view, and Bayes-type algorithms. In the case of an unknown parameter after change the weighted CUSUM and the generalized likelihood ratio (GLR) are discussed. The problem of how algorithms used for detecting changes can improve the tracking ability of an adaptive identification scheme makes a special paragraph. The Chapter ends by a paragraph dedicated to two off-line problem statements: off-line hypotheses and estimation of thechange time.

Chapter 3 of the book is devoted to the presentation of the main results from probability theory, including conditional probability and expectation, Brownian motion and diffusion processes, martingales, stopping times, and to some results from the control literature, namely observers, Kalman filter, and connections between state-space and ARMA models.

Chapter 4 is concerned with some basic results about estimation and information from a mathematical statistics point of view, about statistical hypotheses testing, sequential analysis and formally defines the criteria for designing and evaluating change detection algorithms in both on-line and off-line frameworks.

The main analytical and numerical results concerning the algorithms presented at Chapter 2 are investigated in **Chapter 5**, including properties of the elementary algorithms, CUSUM-type algorithms, GLR algorithm, Bayes-type algoritm . Finally, analytical and numerical comparative results are presented.

Chapter 6 makes an introductory chapter to Part II, and presents the key ideas of this part: additive and non-additive or spectral changes, changes in a regression model, and ARMA model, in a state-space model, and in other models, design of algorithms and properties of the algorithms and detectability.

Chapter 7 extends the key algorithms presented at Chapter 2 to additive changes in more complex models: regression, ARMA, and state-space models. The authors introducegeneral additive changes, statistical tools (extension of the CUSUM-type and GLR detectors) for detecting such changes for regression, ARMA, state-space models, and discuss the diagnosis or isolation problem and the detectability issue, the properties of these algorithms. They also present geometrical tools for change detection and diagnosis and make some links between statistical and geometrical tools.

Chapter 8 addresses the problem of detecting changes in the spectral properties of a scalar signal by using parametric approaches, mainly focused on on-line algorithms. After the introduction of spectral changes and their specificities, it is investigated the general case of conditional probability distributions and are described the main ideas for designing on-line algorithms (CUSUM and GLR approaches and possible simplifications, including local approach). These algorithms are described in the cases of AR and ARMA models. The design of non-likelihood-based algorithms, also using the local approach is presented. The aspects of detectability issue, implementation issues related to the fact that model parameters before and after change are not known, and off-line algorithms using the likelihood approach in connection with on-line algorithms represent topics of the last sections of the chapter.

Chapter 9 is devoted to the spectral changes in the multidimensional case, including the diagnosis problem, and the properties of the detection algorithms in both the scalar and the multidimensional cases. The key detection tools: likelihood ratio, the local approach, and the non-likelihood-based algorithms, emphasising the new multidimensional issues are introduced, and the likelihood-based algorithms of previous chapter are extended to multidimensional AR and ARMA models. A distinct paragraph is dedicated to the application of the non-likelihood-based design of algorithms (on-line and off-line) to the problem of detection and diagnosis of changes in spectral characteristics of multidimensional

signals, or, equivalently, in the eigenstructure of non-stationary multivariable systems. The detectability issue, from a statistical point of view, and the theoretical properties of the various algorithms introduced and in the previous chapters are investigated in the last section of the chapter, and of Part II.

Chapter 10 of the book, which Part III starts with, is devoted to the problems of implementing and tuning change detection algorithms. It starts with the description of a general methodology for implementing and tuning the algorithms, relied on the available theoretical results concerning the properties of the algorithms. It continues with the tuning of all the techniques introduced at Chapter 2 and investigated at Chapter 5, namely the algorithms for detecting changes in the scalar parameter of an independent sequence. The case of a vector parameter and a linear decision function, and the case of a quadratic decision function are dealt with in the last two paragraphs of the Chapter.

Chapter 11 illustrates the use of change detection algorithms and gives examples of potential application of the change detection methodology. The first type of examples includes fault -detection in inertial navigation systems, onset detection in seismic signal processing, continuous speech signals segmentation, and vibration monitoring. The examples of the second type are related with statistical quality control, biomedical signal processing, and fault -detection in chemical processes.

Each chapter concludes with notes and bibliographical references to the problems discussed and with a summary of the key results. References at the end of the book mainly indicate essential literature for the subject concerned. A Subject Index constitutes the last Part of the book.

Two main paths are suggested by the authors for the reader: one focussing on the investigation of the algorithms and the other one focussing on the practical design and applications. For the reader willing to take the first path, the authors recommend to start with the design of the algorithms, proceed through the properties, and finally reach tuning and applications. The reader interested mainly in the practical design and application of the algorithms can start with the applications, which he will select from his path through the other chapters.

The reader is assumed to have some background in probability, random processes, linear algebra, linear systems theory. Some mathematical maturity is essential. The mathematical statistics results are not all derived and the reader is directed to other books or papers to complete mathematical results and proofs.

The material presented in the book is very well organized, presented with clarity, and the reader's understanding is helped with some examples. It is worth mentioning the fluency of the style, the absence of typographical errors and the accuracy of graphical material, which make the book an agreeable reading. From a pedagogical point of view, there is much merit in this book.

Finally, I reaffirm my conviction of the uniqueness of the book in terms of its selected topics and the approach made, and I strongly recommend it to researchers and practitioners in the field of change detection in signals and systems, who will certainly find this book an important reference.

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