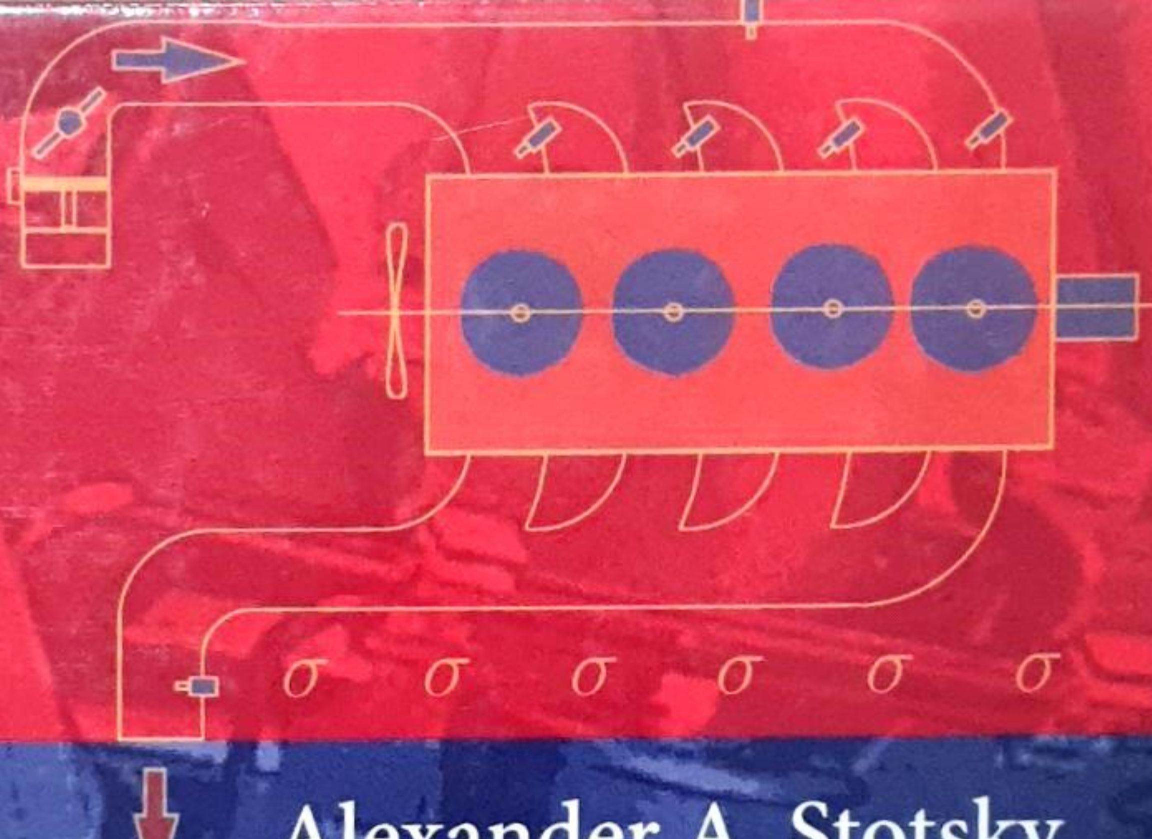

Alexander A. Stotsky

Automotive Engines

CONTROL, ESTIMATION, STATISTICAL DETECTION

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Preface

Increasing requirements for a fuel economy, exhaust emissions and the output performance and also the complexity of the automotive engines necessitate the development of a new generation of the engine control functionality. This book offers the solutions of a number of the engine control and estimation problems and consists of ten Chapters grouped in four Parts. Idle speed control and cylinder flow estimation techniques are presented in the first Part of the book; engine torque and friction estimation methods are presented in the second Part; engine misfire and Cam Profile Switching diagnostic methods are presented in the third Part; and engine knock detection and control algorithms are discussed in the fourth Part of the book. The algorithms presented in the first Part of the book use a mean value engine model and the techniques described in the rest of the book are based on the cylinder individual engine model. The book provides a sufficiently wide coverage of the engine functionality.

The book also offers a tool-kit of new techniques developed by the author which was used for the problems described above. The techniques can be listed as follows: input estimation, composite adaptation, spline and trigonometric interpolations, a look-up table adaptation and a threshold detection adaptation. These methods can successfully be used for other engine control and estimation applications. These methods are listed in Table 0.1 and Table 0.2 which contain a brief description of the methods, application areas and references providing a reader with the overview and a guidance through the book.

One of the key techniques used in this book is the statistical techniques. A periodic nature of the engine rotational dynamics and a cycle-to-cycle variability allows the presentation of the engine signals as statistical signals utilizing such statistical variables as mean values and standard deviations. The detection of the engine events such as misfire events, knock events and others can be associated with the statistical hypotheses. The statistical hypotheses can in turn be tested via decision making procedures, described in Table 0.3 for example. Two basic types of errors can be made in the statistical tests of the

Technique	Purpose	References
Input Estimation	Estimation of Unmeasured Input of a Dynamic System from the Output Measurements	[5], [48], [49], [85],[95], [99], [100]
Composite Adaptation	Parameter Estimation Technique Driven by both Tracking and Prediction Error with Improved Convergence Rate	[96], [97], [100]
Recursive Spline Interpolation	A Polynomial Fitting of Measured Signal in the Least-Squares Sense and Analytical Calculation of the Derivatives with a High Accuracy.	[90], [93], [102]
Trigonometric Interpolation	Calculation of the Frequency Contents of the Oscillating Signal in a Moving Window	[86], [87], [88],[105]
Look-Up Table Adaptation	Adaptation of the Engine Look-up Tables with Meager New Data Representation	[89],[90], [107], [108]
Detection Threshold Adaptation	Event Misdetection Avoidance via Adaptation of the Detection Threshold of the Signal Using a Confidence Interval Method	[91], [92]

Table 0.1. Techniques

Technique	Described in Chapter	Application	Applied in Chapter
Input Estimation	2.2.1	Idle speed control, Cylinder Flow Estimation	1, 2
Composite Adaptation	2.3.1	Cylinder Flow Estimation	2
Recursive Spline Interpolation	3	Engine Acceleration Estimation	3,4
Trigonometric Interpolation	4.3, 7.2	Torque Estimation, Misfire Diagnostic, Knock Detection	4, 7, 9
Look-Up Table Adaptation	5.5, 6.3	Adaptation of the Engine Friction Look-Up Table	5,6
Detection Threshold Adaptation	10.5	Adaptation of the Engine Knock Detection Threshold	10

Table 0.2. Application of Different Techniques

hypotheses called α-risk and β-risk specified by the engineer. The detection performance of the engine events such as misfire events, knock events and others can in turn be associated with these errors, for example with α-risk. The same detection performance (with the same α-risk) can be achieved if the parameters of the signal such as a mean value and a standard deviation involved in the detection of the engine events change due to aging of the engine components, for example. Many types of the engine event detection problems can be formulated as hypothesis-testing problems aiming to a robust detection providing the same detection performance for new and aged engines. A great potential for a robust engine control system design is in a combination of statistical hypotheses and a feedback principle. A control aim can also be associated with the statistical hypothesis and the feedback can be used for either rejection or not rejection of a null hypothesis. A tracking error which is driven to zero via a proper choice of a feedback loop could be presented as a difference between the value of the statistic associated with a hypothesis test and a desired value of the statistic. A desirable hypothesis achieved by a feedback when the tracking error converges to zero, in turn determines desired statistical properties of the closed loop system. For example, the rejection of a null hypothesis in favor of the alternative hypothesis achieved by the engine knock feedback described in Chapter 10 offers a desired statistical separation between a mean value of the maximum amplitude of the knock sensor signal at a given frequency and the threshold value. This in turn, allows the design of a robust engine knock control system with desired α-risk and probability of the knock occurrence. These statistical methods are not only used widely in the book in Chapters 6-10, but also collected and described in Appendix as the most future prospective methods for a new generation of a robust engine functionality. The statistical methods are also listed in Table 0.3 providing references to the description of the method and application areas. This book is one of the first steps towards a statistical robustification of the engine control functionality.

The major part of the book is devoted to the real-time algorithms, and Chapter 9 is devoted to the statistical automatic calibration of the engine knock detection algorithm. Rising number of the engine calibration parameters and a time and cost associated with the engine calibration necessitate the development of a software for automatic calibration of the engine functionality. Automatic engine calibration is a rapidly growing area and Chapter 9 of the book shows an example for the statistical automatic calibration of the engine knock frequency.

Practising automotive engineers should find this book useful when they need the solutions of engine control and estimation problems described in this book, or when they are working on a new engine control or estimation problem and want to use the techniques described in this book. Black Belts working in automotive industry should also find the book useful due to the comprehensive collection of the statistical techniques and their applications to the automotive engines. Engine functionality forms the part of the Automotive Engineering Courses at Universities. This book should also be useful for lecturers, researchers and students since it provides a sufficiently wide coverage of the engine control and estimation problems, detailed descriptions of the techniques useful in automotive applications, and also describes future trends and challenges in the engine functionality.

The author is grateful to his colleagues from Chalmers University, Ford Motor Company and Volvo Car Corporation for interesting discussions. The

Statistical Method	Described in Chapter	Application	Applied in Chapter
One Sample t-Test	14.1.1	Misfire Detection, Knock control	7,10
Two Sample t-Test	14.1.2	Knock detection	9
Test For Equal Variances	14.1.3	Look-up tables adaptation	6
Outlier Detection Test	14.1.6	Knock Control	10
Confidence Intervals as Thresholds	14.1.6	Knock Control	10
Markov Inequality	10.3.2	Knock Control	10
Random Number Generators	10.2.1	Knock Modeling & Control	10

Table 0.3. Application of the Statistical Methods

statistical part of this work was carried out within the Volvo Six Sigma Programme.

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