Intelligent Signal Processing

Edited by

SIMON HAYKIN • BART KOSKO

INTELLIGENT SIGNAL PROCESSING

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INTELLIGENT SIGNAL PROCESSING

This book is dedicated to Bernard Widrow
for laying the foundations of adaptive filters

Preface

This expanded reprint volume is the first book devoted to the new field of intelligent signal processing (ISP). It grew out of the November 1998 ISP special issue of the *IEEE Proceedings* that the two of us coedited. This book contains new ISP material and a fuller treatment of the articles that appeared in the ISP special issue.

WHAT IS ISP?

ISP uses learning and other "smart" techniques to extract as much information as possible from incoming signal and noise data. It makes few if any assumptions about the statistical structure of signals and their environment. ISP seeks to let the data set tell its own story rather than to impose a story on the data in the form of a simple mathematical model.

Classical signal processing has largely worked with mathematical models that are linear, local, stationary, and Gaussian. These assumptions stem from the precomputer age. They have always favored closed-form tractability over real-world accuracy, and they are no less extreme because they are so familiar.

But real systems are nonlinear except for a vanishingly small set of linear systems. Almost all bell-curve probability densities have infinite variance and infinite higher order moments. The set of bell-curve densities itself is a vanishingly small set in the space of all probability densities. Real-world systems are often highly nonlinear and can depend on many partially correlated variables. The systems can have an erratic or impulsive statistical structure that varies in time in equally erratic ways. Small changes in the signal or noise structure can lead to qualitative global changes in how the system filters noise or maintains stability.

ISP has emerged recently in signal processing in much the same way that intelligent control has emerged from standard linear control theory. Researchers have guessed less at equations to model a complex system's throughput and have instead let so-called "intelligent" or "model-free" techniques guess more for them.

Adaptive neural networks have been the most popular black box tools in ISP. Multilayer perceptrons and radial-basis function networks extend adaptive linear combiners to the nonlinear domain but require vastly more computation. Other ISP techniques include fuzzy rule-based systems, genetic algorithms, and the symbolic expert systems of artificial intelligence. Both neural and fuzzy systems can learn with supervised and unsupervised techniques. Both are (like polynomials) universal function approximators: They can uniformly approximate any continuous function on a compact domain, but this may not be practical in many real-world cases. The property of universal approximation justifies the term "model free" to describe neural and fuzzy systems even though equations describe their own throughput structure. They are one-size-fits-all approximators that can model any process if they have access to enough training data.

But ISP tools face new problems when we apply them to more real-world problems that are nonlinear, nonlocal, nonstationary, non-Gaussian, and of high dimension. Practical neural systems may require prohibitive computation to tune the values of their synaptic weights for large sets of high-dimensional data. New signal data may require total retraining or may force the neural network's vast and unfathomable set of synapses to forget some of the signal structure it has learned. Blind fuzzy approximators need a number of if-then rules that grows exponentially with the dimension of the training data. This volume explores how the ISP tools can address these problems.

Organization of the Volume

The 15 chapters in this book give a representative sample of current research in ISP and each has helped extend the ISP frontier. Each chapter passed through a full peer-review filter:

1. Steve Mann describes a novel technique that lets one include human intelligence in the operation of a wearable computer.
2. Sanya Mitaim and Bart Kosko present the noise processing technique of stochastic resonance in a signal processing framework and then show how neural or fuzzy or other model-free systems can adaptively add many types of noise to nonlinear dynamical systems to improve their signal-to-noise ratios.
3. Malik Magdon-Ismail, Alexander Nicholson, and Yaser S. Abu-Mostafa explore how additive noise affects information processing in problems of financial engineering.
4. Partha Niyogi, Fredrico Girosi, and Tomaso Poggio show how prior knowledge and virtual sampling can expand the size of a data set that trains a generalized supervised learning system.
5. Kenneth Rose reviews how the search technique of deterministic annealing can optimize the design of unsupervised and supervised learning systems.
6. Jose C. Principe, Ludong Wang, and Mark A. Motter use the neural self-organizing map as a tool for the local modeling of a nonlinear dynamical system.
7. Lee A. Feldkamp and Gintaras V. Puskorius describe how time-lagged recurrent neural networks can perform difficult tasks of nonlinear signal processing.
8. Davide Mattera, Francesco Palmieri, and Simon Haykin describe a semiparametric form of support vector machine for nonlinear model estimation that uses prior knowledge that comes from a rough parametric model of the system under study.
9. Yann LeCun, Léon Bottou, Yoshua Bengio, and Patrick Haffner review ways that gradient-descent learning can train a multilayer perceptron for handwritten character recognition.
10. Shigeru Katagiri, Biing-Hwang Juang, and Chin-Hui Lee show how to use the new technique of generalized probabilistic gradients to solve problems in pattern recognition.
11. Lee A. Feldkamp, Timothy M. Feldkamp, and Danil V. Prokhorov present an adaptive classification scheme that combines both supervised and unsupervised learning.
12. J. Scott Goldstein, J.R. Guescin and I.S. Reed describe an algebraic procedure based on reduced rank modeling as a basis for intelligent signal processing
13. Simon Haykin and David J. Thomson discuss an adaptive procedure for the difficult task of detecting a nonstationary target signal in a nonstationary background with unknown statistics.
14. Robert D. Dony and Simon Haykin describe an image segmentation system based on a mixture of principal components.
15. Aapo Hyvärinen, Patrik Hoyar and Erkki Oja discuss how sparse coding can denoise images.

These chapters show how adaptive systems can solve a wide range of difficult tasks in signal processing that arise in highly diverse fields. They are a humble but important first step on the road to truly intelligent signal processing.

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