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Scanning the Issue

SPECIAL ISSUE ON DETECTION THEORY

This special issue of the PROCEEDINGS is devoted to that branch of information theory known as detection theory—its basic outlines, recent theoretical developments, and areas of application.

Detection theory may be defined as the science of evaluating and synthesizing signal-processing systems which operate on mixtures of signal and noise so as to either measure something about the signal (for example the range of a radar target) or to decide between alternatives about it (for example, whether a radar receiver observed signal plus noise or noise alone, or whether a communication receiver received one letter of the alphabet or another).

The theoretical outlines were first presented in the 1930's by statisticians faced with randomness in their data while deciding between alternatives or while making measurements. The applicability of this point of view was soon recognized and exploited by engineers as part of the general perception, accompanying World War II electronics developments, that randomness was the key to information handling. Since that time there have been many explorations of theoretical questions (which the reader interested in inquiring further may read about in the IEEE TRANSACTIONS ON INFORMATION THEORY) and of practical applications (the TRANSACTIONS of the Communication Technology, Aerospace and Electronic Systems, Geoscience Electronics, and Audio and Electroacoustics Groups are particularly relevant).

The publication of this special issue comes about almost exactly a quarter century after the basic ideas were first injected into the mainstream of electronics engineering, and is thus perhaps an appropriately timed attempt to take stock of the field. During this period there have been many extensions of the basic theory to wider classes of situations, and there have been many interesting solutions to problems arising in fields as varied as astronomy, psychophysics, seismology, and management decision-making, in addition to the more familiar radar, sonar, and communication areas.

This issue begins with a feature invited paper by W. L. Root (Part I) describing in tutorial language the elements of the "classical" theory of detection and estimation. This form of the theory, roughly equivalent to the results available in the mid-50's, is sufficient to handle those problems in which one may assume that the signals are particularly simple, that the noise is of a certain idealized form (Gaussian), and that the statistics of signal and noise are known exactly.

In Part II advances in the underlying theories are presented, dealing for the most part with more sophisticated approaches aimed at broadening the area of applicability beyond the restrictions of the classical case. Part III treats selected application areas in which detection theory has been applied as a useful tool.

In many practical instances the statistics of the noise will not be known, so that one runs a considerable risk, if he uses a system optimized for Gaussian statistics, of very poor performance in practice. Or perhaps the Gaussian assumption is reasonable, but the optimum structure is too complicated. The paper by J. B. Thomas surveys the *nonparametric* approach, in which next to nothing is assumed known about the noise; relatively simple systems then result which, while nonoptimum, may nonetheless be expected to work not too badly over a wide range of conditions.

The next paper, by R. A. Howard, serves two functions. It introduces the notions of what in management schools is called *decision analysis*, a systematic way of taking into account the available but imperfect information in making decisions. The reader will perceive that this area, which has evolved independent of detection theory, is in many ways structurally identical to it. The second accomplishment of Professor Howard's paper is to point out how one may best make use of imperfect knowledge of the statistics in a decision problem. The state of a priori knowledge may range between the complete-statistics-available classical situation and the no-statistics-available nonparametric situation.

One of the nice things about the theories that are the subject of this issue is that one may often determine how well a decision or estimation can be carried out without actually having to derive in detail how it is done. L. P. Seidman presents a concise summary of the present state of knowledge concerning the smallest achievable error in making measurements (parameter estimates) on a noisy signal. This has proved to be a difficult problem in the most common practical cases in which the signal is not necessarily a linear function of the parameter to be measured.

The next three papers survey three recent attempts to imbed classical statistical estimation and detection theory in a more general framework of sufficient power so that a variety of highly nonclassical issues can be dealt with. For example, in practice the signal may not be constant but may fluctuate; it may be disturbed by multipath smearing or by random nonlinearities; the noise may be non-Gaussian; its statistics may be nonstationary; it may be introduced in a nonadditive way; and so forth. In such cases the classical theory is simply not able to arrive at clean-cut mathematical results that are interpretable in terms of signal-processing structures.

H. L. Van Trees discusses in his paper the exploitation of *state variable* ideas, first introduced in automatic control theory. He employs these ideas to give a unified treatment of problems involving signals received over fluctuating multipath channels (e.g., ionospheric communication or planetary radar reflections).

There is, of course, an infinite number of ways in which a random process can be non-Gaussian. R. L. Stratonovich has developed methods for dealing with an important class of problems in which the noise and/or the signal are non-Gaussian in a certain way, and in which the way noise and signal are combined is not necessarily simple addition.

T. Kailath discusses an approach in which, if one views the signal or random noise process in a novel way, a number of difficulties are circumvented, and a number of the classical results appear as special cases. The technique involves working not with the random process but with its *innovations process*, which may be thought of as that white Gaussian noise which, if it were to be passed through a suitable, filter, not necessarily linear, would produce the original process.

The final theoretical paper, by D. Middleton, treats the extension of the classical theory to include the spatially distributed character of the transmitting, propagating, and receiving structures. Thus, in principle, one may synthesize optimum transmitting and receiving array (antenna) structures, as well as the usual signal-processing receiver elements.

The set of applications papers begins with an object lesson. M. R. Schroeder reviews many years' experience in devising effective ways of measuring some of the parameters of human speech signals. He recounts a number of instances in which approaches which were theoretically sophisticated but insufficiently motivated practically came to nought, while success was finally achieved by clever more heuristic approaches. Not all areas in which applications of detection theory have been attempted have proved so refractory, yet it is still true that a good physical view of the problem, although not always sufficient, is always necessary.

The performance of human receptors has been studied extensively by psychophysicists, and their experience in using detection theory is related next by D. M. Green. Useful insights about reasonable system models of, for example, the human auditory system have been gained by comparing experimental results on just-discriminable stimuli with theoretical predictions. In a more particularized study in this same area, W. M. Siebert's paper derives a theoretical lower bound on frequency discrimination

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available from neural signal transmission, compares it with data on human subjects, and uses the results in deciding between two competing models for the neural aspects of the sensory apparatus.

Turning to radar, we first come to the notion of sequential detection, which is surveyed by J. J. Bussgang. The idea here is that one can effect a saving (in average time to get a series of reliable decisions, for example) if instead of using a fixed duration for each successive test interval (at the end of which a decision is made), one lets each test interval run until a sufficiently unambiguous indication is built up and then goes on to the next test interval. This idea is applicable to a wide class of situations but has seen most frequent use in search radars.

In radio and radar astronomy a rich variety of situations arises in which the signal from a radiating or reradiating object must be detected in noise or in which some attribute of astronomical interest must be measured. Hagfors and Moran present a comprehensive survey of the numerous detection and estimation techniques that have been evolved for studying problems peculiar to specific types of astronomical objects.

Detection theory and estimation theory have played an important role in the recent development of certain branches of seismology, particularly in the use of spatially distributed arrays of seismometers for monitoring remote earthquakes and underground nuclear explosions, and for geophysical prospecting using local explosion sources. The seismic array signal-processing area is surveyed by J. Capon in connection with the use of "large-aperture" arrays (several hundred kilometers) for the monitoring problem. The emphasis is on optimum techniques of detecting an incident signal, estimating its waveform, and measuring its decomposition according to arrival direction and velocity.

In the next paper, G. O. Young and J. E. Howard deal with a problem which similarly involves detection and determination of the spatial character of the received signal. Their objective is to design the signal-processing system for a pulse radar that uses an array antenna to detect and measure angular positions of several individual targets simultaneously.

The last paper deals with a communication problem. K. Abend and B. D. Fritchman discuss one approach to improving the reception of signal sequences when both noise and intersymbol time smearing are present, as is often the case with telephone line transmission, for example.

By design we have omitted from this issue one important contemporary area in which significant new detection theory formulations have been evolved and applications made, the exploitation of quantum communication channels. This large and very active field will be treated in the September 1970 special issue of the PROCEEDINGS devoted to optical communications.

This detection-theory issue was planned and prepared with the advice and assistance of an editorial committee consisting of Robert Price and David Slepian. I would like to express my appreciation to them, to the authors, and to the many reviewers who helped contribute to the quality of this volume.

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