Stochastic optimal control and its connection with estimation

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Abstract: The paper describes a formulation of the stochastic control problem in which the primary and secondary performance indices are distinguished. A minimisation and averaging principle, defining the connection between the two indices, is established, and some conclusions resulting from the principle are described. The generalised certainty equivalence principle, in some new notation, is also presented. Finally, the original generalised recursive estimation problem, which is equivalent to the stochastic optimal control problem, is formulated and solved.

1 Introduction

Many papers have been written about the stochastic optimal control problems where the available information is incomplete and the mean value of a performance index is minimised. A stochastic version of dynamic programming is sometimes used to solve such problems [1–17]. This requires certain assumptions about changing the order of minimisation and averaging operations which, in many papers, are not sufficiently exactly expressed.

The present paper contains some of the author's results, most of which are published in Polish [6–11]. In Sections 2 and 3 the problem is formulated and primary and secondary performance indices are distinguished. In Section 4 the solution of the problem is described and the so-called minimisation and averaging (Min-E) principle formulated. Section 5 contains conclusions resulting from the Min-E principle. In Section 6 the original description of the generalised certainty equivalence principle is presented. In Section 7 the generalised recursive estimation problem is formulated and solved; it is also shown that the last problem is equivalent to the stochastic optimal control problem.

2 Description of primary problem

Let us consider a system described by the difference equation

$$x_{n+1} = f_n(x_n, u_n, w_n) \qquad (1)$$

where x_n, u_n, w_n are the vectors of state, control and disturbance, respectively, f_n are definite functions of their arguments, n denotes discrete time, i.e. $n = 0, 1, \ldots, N$, and N is an integer defining the stopping time.

The primary performance index, which we would like to minimise, has the form

$$I = \sum_{n=0}^{N} L_n(x_n, u_n, v_n) \qquad (2)$$

where v_n are vector random variables and L_n are scalar definite functions.

We assume that the control variables u_n do not influence the random variables w_k, v_k for $k > n$, $k, n = 0, 1, \ldots, N$. We also assume that the appropriate probability distribution functions for random variables w_n, v_n and the initial state x_0 are given.

Because the primary problem contains a large number

of random variables the primary performance index (eqn. 2) also takes a random value. Thus, in the case of incomplete information it is impossible to find the solution of the primary problem, i.e. to define the controls u_n for which the primary performance index takes its minimal value. The formulation of a secondary problem, which will be soluble, depends upon the available information.

3 Secondary problem formulation

We assume that the information about the system consists of two parts. The first part results from past experience and takes the form of appropriate probability distribution functions; the second part results from current measurements to be made in the system and takes the form of a vector of current information $\bar{y}_n$. This vector $\bar{y}_n$ contains information available at the time n and obtained from measurements. We assume that the vector $\bar{y}_n$ accumulates results of measurements from the past, i.e. all components which occur in the vector $\bar{y}_{n-1}$ also occur in the vector $\bar{y}_n$, together with the results of current measurements $\bar{y}_n$. The above assumption is made only to concentrate the mind; there is no necessity to make this assumption, e.g. in the case when the current measurements $\bar{y}_n$ obtained in each step contain the variables x_n, v_n and form Markov processes. Generally speaking, the components of the vectors $\bar{y}_n$ should be chosen so that it will be possible to define the appropriate probability distribution functions which are used at the time of performing the conditional averaging operations to be defined later.

Let $\bar{Y}_n$ and U_n be the sets of vectors $\bar{y}_n$ and u_n, respectively, i.e. $\bar{y}_n \in \bar{Y}_n$ and $u_n \in U_n$, $n = 0, 1, \ldots, N$. The sequence of the functions $u_n = h_n(\bar{y}_n)$, $n = 0, 1, \ldots, N$, each of which maps $\bar{Y}_n$ into U_n, and for which the secondary performance index of the form

$$\bar{I}(h) = E \sum_{n=0}^{N} L_n[x_n, h_n(\bar{y}_n), v_n] \qquad (3)$$

takes a definite value, will be called the admissible control strategy. Here E denotes the operation of averaging and the notation $\bar{I}(h)$ has been introduced to stress that the value of the secondary performance index depends upon the set of functions $h = [h_0^T, h_1^T, \ldots, h_N^T]^T$.

Secondary problem

Among admissible control strategies of the considered system the optimal strategy $u_n = h_n^o(\bar{y}_n)$, $n = 0, 1, \ldots, N$, is to be found for which the secondary performance index takes its minimal value, i.e.

$$\bar{I}(h^o) = \underset{h}{\text{Min}} \; \bar{I}(h) \qquad (4)$$

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