CHAPTER - 1

A REVIEW OF BASIC CONCEPTS

This chapter, besides giving a brief summary of literature in this and related fields, introduces the concepts leading to spectral factorization. The chapter concludes with a brief summary of the material presented in later chapters.

1.1 THE BASIC COMPONENTS OF THE ALGORITHM

The multivariable spectral factorization algorithm, as presented in this Thesis, is a cascade of three component algorithms. In the first of these, the external representation (estimates of the matrix covariance sequence) of a joint (gaussian) process is linked with its internal representation, that is, by a finite dimensional gauss-markov process. In the second component algorithm, from the set of all such markovian representations, the particular one which gives rise to the unique stable, inverse stable spectral factor is pinpointed. In the third and final component algorithm, the obtained state representation is converted to a (discrete) transfer (function) matrix or auto-regressive moving-average (ARMA) model. This, in brief, is our desired spectral factorization.

The following alternative interpretation might help to clarify the rationale of the above algorithm. The parametric estimation problem has been viewed as a stochastic modelling problem, that is, finding a representation of the observed joint process as the output of a causal and causally invertible linear system driven by white noise. The significance of this essentially unique representation in the context of a joint process follows.

Two processes are termed strongly (resp. weakly) feedback free when the above canonical innovations representation (IR) of the joint process has one of the two specified structures respectively as pointed out by Caines[16]. This property also has an equivalent characterization in terms of the spectrum of the joint process. These characterizations yield a set of statistical tests for feedback. When feedback exists it is still possible to identify the separate loops from the IR by a rational matrix inversion. However, it is only when the disturbances in each loop are mutually orthogonal, and one of the loops contains a delay, that the loops so identified constitute the forward and feedback loops of the observed physical process. Our aim is to address the spectral factorization algorithm to this problem of closed loop system identification.

Coming to the cascade construction of the algorithm, the first component algorithm is immediately recognizable as the minimal realization algorithm of linear system theory. We have used Rissanen's recursive algorithm[70,71] to find nested solutions for increasing length of the (matrix) covariance sequence. The set $\mathbb{P}$ (where P stands for the covariance of the markov process) of all such markovian representations is characterized by Positive Real Lemma (PRL) as enunciated by Anderson[5] and Faurre[27]. Faurre[27] has investigated the structure of $\mathbb{P}$, a closed convex set, which has a maximum, P^* and a minimum P_*. It can be further shown that P_* corresponds to the strong (Wiener) factorization of the spectrum. Accordingly, the second component algorithm uses an iterative routine which closes on P_* and yields the necessary data for the strong, that is, stable and inverse stable, spectral factor. In the final component algorithm, we use Leverrier's algorithm[89] to change the matrix quadruple description to the transfer matrix one. Incidentally, Leverrier's algorithm has several times been resurrected in the past, for example, by Sauriau and Frame. An alternative is Sauriau-Frame-Fadeeva algorithm[26,100]. In the next few sections, we try to place our problem in its proper historical perspective.

1.2 FEEDBACK SYSTEM IDENTIFICATION

It is frequently desirable and often necessary to perform process identification experiments in engineering, in closed loop. The reasons are :

i) process behaviour is unstable or poor without control ;

ii) the risk of process damage, production loss or reduction in efficiency, if the feedback loop is opened ; and

iii) a variational model around an operating point is needed.

Besides, there are systems which are inherently in closed loop and there is no physical means of opening the feedback loop. Most of the economic models and biological systems come under this category. The particular applied problem we have chosen for study, that is, the identification of the power system load model, needs a closed loop study for reasons stated above.

The most informed review of the literature on closed loop system identification till to date, is by Gustavsson, Ljung and Soderström[32]. This review

i) examines the difficulties encountered in closed loop system identification with reference to set of models, identification methods and experimental conditions ;

ii) surveys critically the previous results in the field ; and

iii) outlines explicit necessary and sufficient conditions for system identifiability for the single-input single-output case with feedback.

However, we critically examine the available identification methods and their extension to closed loop case elsewhere in this Thesis.

1.3 JOINT PROCESS CONCEPT

The important single idea that has given a new dimension to the solution of closed loop system identification problem is the joint input-output process representation as a time series of noise sources. The idea was contained in Caines and Wall's[15] work. It was later expanded by Caines and Chan[16] and ultimately developed into a tight-knit mathematical definition for feedback free (resp. feedback) processes. The definition also leads to statistical methods of identification of the physical system provided certain conditions are met.

The present work is based on the same premises (cf. Caines and Sinha[18]). Until now Caines' basic feedback structure determination was by prediction error methods only. The present work seeks to realize the feedback structure by spectral factorization method. The spectral factorization algorithm for the multivariate case, till to-date, is virtually non-existent. Our modest claim is that tangible results of acceptable accuracy and a fool proof algorithm of multivariate spectral factorization are being reported for the first time.

The idea of using the joint input-output process for closed loop system identification has also appeared elsewhere. For example, Lindahl and Ljung[52] introduced the approach to treat all measured variables as outputs from a dynamical system driven by noise only. But the approach was neither convincingly put forward nor pursued later. Incidentally, they have used the prediction error methods, maximum likelihood estimation (MLE) method for identification of their joint process model. Only recently, Phadke and Wu[65] again used the joint process representation for determining the transfer function and noise model of a blast furnace from closed loop data.

However, only in the preceding works mentioned in paragraph 1 of this section and partly in this work, the joint process representation has been explored with complete mathematical rigour to expose the feedback structure. Also to the knowledge of the author, so far the joint process representation has not been found out by any other method except the prediction error methods.