Orthogonal rational functions on the unit circle: theory, applications and generalizations*

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Abstract

We give a survey of the basic theory of orthogonal rational functions with poles outside the unit disk. We give a motivation by linear prediction and signal processing applications. We include the basic theory of recurrence relations, Christoffel-Darboux relations, reproducing kernels, associated functions and interpolation properties, para-orthogonal functions and quadrature, moment problems and Favard theorems, and convergence properties.

We touch only briefly on the following related and generalized topics. We give an indication of related results for the case where the poles (interpolation points) are on the boundary (i.e. the circle). We briefly consider the case where the functions are matrix valued and relate it to tangential interpolation problems. Some results are mentioned for the case where the inner product is taken w.r.t. a Gramm matrix which is quasi Toeplitz and finally we mention related results about time-varying systems.

1   Motivation (linear prediction)

Let $s = (s_n) \in \ell_2$ be a discrete signal. Its Fourier transform $S(e^{i\omega}) \in L_2$ is called its *spectrum*, while we call $R(e^{i\omega}) = |S(e^{i\omega})|^2$ the *power spectrum*. Defining $S_*(z) = \overline{S(1/\bar{z})}$, we can write this as $R(t) = S(t)S_*(t)$ with $t \in \mathbb{T} = \{z \in \mathbb{C} : |z| = 1\}$. When $R(z) = \sum_k r_k z^k$, then we call the sequence $r = (r_k)$ the *autocorrelation function* of the signal s. Obviously $r_n = \sum_k s_{n+k}\bar{s}_k = \bar{r}_{-k}$, $n \in \mathbb{Z}$. The *energy* of the signal corresponds to $r_0 = \|s\|^2 = \|S\|^2$. In the linear prediction problem, we want to predict the value of s_n from its past, i.e., by the estimate $\hat{s}_n = -\sum_{k \geq 1} a_k s_{n-k}$. Assume that the signal is in a stationary regime, so that the a_k do not depend on n. The corresponding prediction error is $e_n = s_n - \hat{s}_n = \sum_{k \geq 0} a_k s_{n-k}$ or in the frequency domain: $E(z) = A(z)S(z)$, with $a_0 = A(0) = 1$. The best possible such a model in least squares sense is the one which minimizes $\|e\|^2 = \|E\|^2 = \|AS\|^2 = \|A\|_R^2$

Orthogonal Rational Functions

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Table of Contents Orthogonal Rational Functions

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