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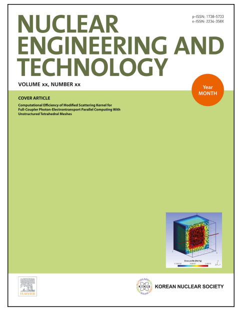

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Wavelet Operator for Multiscale Modeling of Nuclear Reactor

Vineet Vajpayee, Siddhartha Mukhopadhyay, and Akhilanand Pati Tiwari

***Abstract*—This paper introduces a methodology of designing wavelet operator suitable for multiscale modeling. The operator matrix transforms states of a multivariable system onto projection space. Additionally, it imposes a specific structure on the system matrix in multiscale environment. To be specific, the paper deals with a diagonalizing transform that is useful for decoupled control of a system. It establishes that there exists a definite relationship between the model in measurement space and that in projection space. Methodology for deriving the multirate perfect reconstruction filter bank, associated with the wavelet operator is presented. The efficacy of the proposed technique is demonstrated by modeling the point kinetics nuclear reactor. The outcome of the multiscale modeling approach is compared with that in single scale to bring out the advantage of the proposed method.**

***Index Terms*—Diagonalizing transform, Filter bank, Multiscale modeling, Nuclear reactor, Wavelets.**

I. Introduction

A nuclear reactor is a complex time-varying system exhibiting multi-time-scale dynamics owing to its large dimensions. This behavior becomes more evident as the system operates through different power regimes. It is well known that modeling using single scale approach leads to ill-conditioning [1]. Over the years, different approaches have been proposed utilizing two-time-scale or three-time-scale properties to solve the modeling and control design problem [2]–[4]. In this work, multiscale property of wavelet basis is utilized to address the issue.

Some works have been reported for modeling, designing controller, and analyzing dynamic properties of nuclear plants using single scale approaches like Auto-Regressive with Exogenous input (ARX), Auto-Regressive Moving Average with Exogenous input (ARMAX), Output Error (OE), and Subspace methods. For instance, Boroushaki et al. [5] used ARX model for identification of reactor core. Parametric modeling approaches (ARX, ARMAX, OE) require that the model structure of the process be known a priori. These techniques may not guarantee global minimum. Further, their complexity increases with the order of the system to be estimated. On the other hand, subspace methods are robust, computationally efficient, and free from non-convergence issues. They have been used in nuclear spectroscopy to identify the poles of a system [6] and for the identification of light charged particles [7]. However, multiscale features may not be modeled correctly by the above discussed techniques. Thus, it is essential to conduct a process visualization and modeling exercise in a multiresolution framework.

Multiscale behavior of a process can be suitably modeled using generalized basis functions in specific wavelet basis functions. The primary advantage of wavelet basis attributes is their ability to estimate a set of low order linear models of a nonlinear or a multiple time-scale system. This is equivalent to breaking down a complex problem into a number of relatively simpler problems each seen at an appropriate resolution. The idea central to this class of modeling methodology is the invocation of multiresolution analysis (MRA) in data driven modeling. MRA with wavelet basis functions was first introduced by Mallat in his pioneering work [8]. The last three decades have seen a number of research works dealing with identification of deterministic and stochastic systems from input-output data projected on wavelet basis functions [9]–[14]. Most existing works in the literature have reported identification of linear time varying models that attempt to linearly approximate the system output, although wavelets are known to provide near optimal nonlinear estimates of signals. Moreover, all the above techniques seem to have ignored well established filter bank theory for output synthesis and have relied more on the linear function approximation approach with wavelet basis, relegating the techniques to off-line identification of the process models. Further, state-space models suitable for designing state feedback control are very rarely found. The limitations of existing techniques justify the need for the development of wavelet operators to transform system states in projection space.

Wavelet-based techniques have found wide application in nuclear engineering for noise removal [15]–[17], transient detection [18], [19], and for modeling and control [20]–[23]. Heo et al. [15] designed a wavelet-PCA based denoising scheme for the estimation of thermal power. Park et al. [16] demonstrated the application of wavelet denoising in water-level control of steam generators. In [17], authors applied wavelets to improve the control performance of a predictive controller. Espinosa-Paredes et al. [18] studied transient instability phenomenon of neutronic power oscillation in a Boiling Water Reactor using wavelet transform. Prieto-Guerrero et al. [19] applied wavelet ridges technique for estimation of decay ratio and to further evaluate stability parameters using real neutronic measurements. In [20], a power spectral density based system identification strategy is designed during a

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