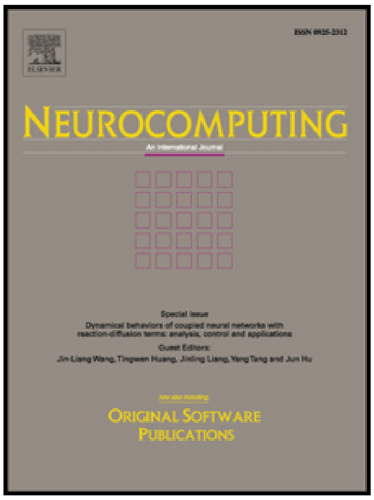
Accepted Manuscript



Modeling for output fiber length distribution of refining process using wavelet neural networks trained by NSGA II and gradient based two-stage hybrid algorithm

Ping Zhou , Mingjie Li , Dongwei Guo , Hong Wang , Tianyou Chai

PII: S0925-2312(17)30095-4
DOI: 10.1016/j.neucom.2017.01.033
Reference: NEUCOM 17931

To appear in: *Neurocomputing*

Received date: 29 March 2016
Revised date: 22 July 2016
Accepted date: 13 January 2017

Modeling for output fiber length distribution of refining process using wavelet neural networks trained by NSGA II and gradient based two-stage hybrid algorithm

Ping Zhou[1,2*], Mingjie Li[1], Dongwei Guo[1], Hong Wang[3], Tianyou Chai[1]

[1] State Key Laboratory of Synthetical Automation for Process Industries, Northeastern University, Shenyang 110819, China
[2] State Key Laboratory of Process Automation in Mining & Metallurgy, Beijing 102628, China
[3] Control Systems Centre, the University of Manchester, Manchester, UK

Abstract: The chemi-thermo-mechanical pulping (CTMP) is an important process that produces fibers for paper-making, whose output fiber length distribution (FLD) directly determines the energy consumption and product quality of the subsequent papermaking production. Therefore, study on modeling and control of the output FLD is essential for improving pulp quality and saving energy in refining process. However, the output FLD of refining process has non-Gaussian stochastic distribution property, making it difficult to use conventional methods to establish the output FLD model effectively. Under the framework of stochastic distribution control theory, this paper presents a novel modeling approach for output probability density function (PDF) of fiber length in CTMP by combining with the improved wavelet neural network (WNN). In this context, the square root B-spline approximation principle is firstly adopted to extract the B-spline weights of fiber length PDF shape as the target outputs for the WNN based B-spline weights model. Secondly, a novel two-stage hybrid learning algorithm is proposed to establish the parameters system for the WNN based weighs model by defining a multi-objective evaluation index for modeling accuracy in advance. This learning algorithm integrates multi-objective NSGA II algorithm in the first stage for better initial solutions at a global scope, and gradient descent method is employed in the second stage for accurate solutions of WNN model parameters inside a local range. As a result, the final output PDF of fiber length is reconstructed by the estimated B-spline weights using the B-spline approximation principle again. Experiments using actual industrial data have demonstrated the superiority and practicability of the proposed method.

Key words: refining process, fiber length distribution (FLD), wavelet neural network (WNN), non-dominated sorting genetic algorithm II (NSGA II), probability density function (PDF), stochastic distribution modeling

1. Introduction

As a key production unit in the chemi-thermo-mechanical pulping (CTMP) production, the refining process converts the chemical impregnated wood chips into individual wood fibers by lateral extrusion and longitudinal fibrillation effect through high speedy discs operation [1]. During the refining process, the output fiber length distribution (FLD) is the most important production index, where it has been shown that the FLD not only affects the dewatering efficiency and thermal energy cost of the follow-up papermaking process, but also directly relates to energy consumption and product quality of the whole pulp and paper production. Therefore, it is particularly important to realize the output FLD modeling and control in refining process so as to optimize product quality and minimize energy consumption [1, 2].

Currently, there are wide ranges of literatures on energy consumption modeling and control in refining processes [2-5]. However, research on modeling and control of the output FLD in refining process has not been reported. Unlike the regular physical parameters in industrial processes, the output FLD in refining process does not follow Gaussian distribution, and exhibits complex stochastic distribution property. This is mainly because the fiber bundles of wood chips into the refiner gradually dissociated into individual wood fiber through lateral extrusion and longitudinal fibrillation of discs, making the final output fiber distribution have strong randomness and uncertainty. Since it is almost impossible to employ a single variable to capture the distribution characteristics of fiber length, at present the approximate statistical mean or variance of the fiber length is used to measure the final pulp quality in practice, albeit it cannot reflect the real distribution characteristics of fibers.

On the other hand, the existing stochastic system control approaches such as minimum variance control and stochastic linear quadratic control all assume that the controlled processes follow Gaussian distributions, and focus on the modeling and control for the mean or variance of the process outputs [6-9]. However, there are many actual industrial control problems, such as jet flame distribution control in boiler systems, paper thickness control in papermaking, and particle size distribution control in polymerization processes whose outputs do not follow Gaussian distributions [6-11]. For these systems with non-Gaussian signals, mean and variance based modeling and control is largely limited and higher order distribution information is required [7]. Thus, it is rather difficult to apply the above mentioned methods to control such stochastic distribution systems. Aiming at the general bounded dynamic stochastic systems that have non-Gaussian distribution stochastic variables, stochastic distribution control (SDC) theory was proposed by Wang in 1996 [6], and has been successfully applied to various types of industrial processes with non-Gaussian stochastic distributions characteristics [6-15]. The SDC focuses on modeling and controlling the shape of the output probability density function (PDF) instead of the mean and variance for non-Gaussian stochastic systems [6, 7], where the objective of SDC is to make the shape of the measured output PDF track a desired PDF. In the pulping and papermaking fields, Wang first used SDC theory to establish the paper web formation control system with PDF shapes of 2D paper solid distribution as feedback signals, and successfully applied in the UK Iggsund Paper Board machine [10].

This paper aims to establish stochastic distribution model of output FLD for refining process based on SDC theory. This stochastic distribution model can not only be used for online estimation of FLD, but can also help to realize SDC of the output FLD in refining process. The existing stochastic distribution modeling methods are usually based on either the least squares identification or the subspace identification, but suffer from low accuracy and weak generalization ability [6,15]. In this paper, by combining the modeling method used in SDC theory with wavelet neural network (WNN) [16, 17], the stochastic distribution modeling of fiber length PDF is transferred into the modeling of B-spline weights which