

Fermentation Process Modeling Using Takagi-Sugeno Fuzzy Model

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Abstract: Fermentation process is vital and important in many biotechnological applications. However modeling the fermentation process is considered a challenging and complex problem. The complexity of the problem is driven by the need of efficient, accurate, not expensive, and reliable predictive models. In this paper, we apply a Takagi-Sugeno Fuzzy Logic technique for modeling the lipase activity production based on nutritional and physico-chemical factors to estimate the lipase activities. The accuracy of the developed fuzzy model is measured, validated and compared with both the multiple regression and artificial neural network models. The fuzzy model successfully showed competitive and promising modeling results.

Key-Words: Fermentation process, Lipase activity production, Takagi-Sugeno Fuzzy Model.

1 Introduction

Lipase production is getting more and more attention in the industry and business field recently due to their biotechnological applications [1]. Lipases have a wide range of uses in industry productions such as dairy-based products, detergents, drugs, cosmetics and leather processes [2]. On the other side, Lipase production is a challenging, complex and not easy to model or monitor [2]. The complexity is due to the nature of lipase production which is highly dependent on its operating conditions that affect its growth. These operating conditions include nutritional and physico-chemical factors such as temperature, initial pH, incubation period, time, inoculum size and agitation rate [1–3]. Consequently, deciding upon an optimization method and choosing a modeling technique are vital issues in the process of producing reliable lipase products with high standards. Efficient optimization and modeling can dramatically improve the system performance and reduce the costs [3].

In biological research, response surface methodology (RSM) is one of the most applied methods in modeling the biological processes. RSM is a statistical and mathematical based system for modeling and optimizing complex processes. RSM explores the relationships between the response (output variable) and the independent variables (input variables). RSM has many advantages such as it reflects the significance of the input variables, alone or in combination, in a given model. Moreover, it reduces the cost of analysis by minimizing the number of experimental trials needed to evaluate input variables and their interactions [4].

Though, RSA is not applicable in all biological applications [3].

In many cases, output results are out of expectations when modeling and predicting systems based on mathematical equations are used for controlling the interactions between the input variables in the process for lipase fermentation. Therefore, a considerable number of previous studies employed empirical models based on artificial intelligence and machine learning approaches. By the following paragraphs we give an insight into some important studies in the field.

Among artificial intelligence and machine learning approaches, Artificial Neural Networks (ANNs) are the most applied in lipase modeling and prediction. In [3] authors used the best composition of production medium among the best previously published media, then they made a comparison by applying both RSM and ANN for optimizing the physical factors for extracellular thermostable lipase production. Although both techniques gave good predictions, the ANN showed better performance in data fitting and estimation capabilities. However ANN in general suffers some disadvantages; ANNs relatively need large amounts of data for training and they work as black input/output box, it is hard to interpret their results.

In [5] ANN model, based on feed forward architecture and back propagation as training algorithm was applied to predict the state of batch fermentations with grape juice extracted from grape waste. The Levenberg- Marquardt optimization technique has been used to upgrade the network by minimizing the sum square error (SSE). Authors found that the best performance of the model for predicting cell

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Instrument Engineers' Handbook, Volume Two Bela G. Liptak, 2018-10-08 The latest update to Bela Liptak's acclaimed bible of instrument engineering is now available Retaining the format that made the previous editions bestsellers in their own right the fourth edition of Process Control and Optimization continues the tradition of providing quick and easy access to highly practical information The authors are practicing engineers not theoretical people from academia and their from the trenches advice has been repeatedly tested in real life applications Expanded coverage includes descriptions of overseas manufacturer's products and concepts model based optimization in control theory new major inventions and innovations in control valves and a full chapter devoted to safety With more than 2000 graphs figures and tables this all inclusive encyclopedic volume replaces an entire library with one authoritative reference The fourth edition brings the content of the previous editions completely up to date incorporates the developments of the last decade and broadens the horizons of the work from an American to a global perspective B la G Lipt k speaks on Post Oil Energy Technology on the AT T Tech Channel

Multiple Model Approaches To Nonlinear Modelling And Control R Murray-Smith, T. Johansen, 2020-11-25 This work presents approaches to modelling and control problems arising from conditions of ever increasing nonlinearity and complexity It prescribes an approach that covers a wide range of methods being combined to provide multiple model solutions Many component methods are described as well as discussion of the strategies available for building a successful multiple model approach

Iterative Learning Stabilization and Fault-Tolerant Control for Batch Processes Limin Wang, Ridong Zhang, Furong Gao, 2019-03-18 This book is based on the authors research on the stabilization and fault tolerant control of batch processes which are flourishing topics in the field of control system engineering It introduces iterative learning control for linear nonlinear single multi phase batch processes iterative learning optimal guaranteed cost control delay dependent iterative learning control and iterative learning fault tolerant control for linear nonlinear single multi phase batch processes Providing important insights and useful methods and practical algorithms that can potentially be applied in batch process control and optimization it is a valuable resource for researchers scientists and engineers in the field of process system engineering and control engineering

Predictive Approaches to Control of Complex Systems Gorazd Karer, Igor Škrjanc, 2012-09-20 A predictive control algorithm uses a model of the controlled system to predict the system behavior for various input scenarios and determines the most appropriate inputs accordingly Predictive controllers are suitable for a wide range of systems therefore their advantages are especially evident when dealing with relatively complex systems such as nonlinear constrained hybrid multivariate systems etc However designing a predictive control strategy for a complex system is generally a difficult task because all relevant dynamical phenomena have to be considered Establishing a suitable model of the system is an essential part of predictive control design Classic modeling and identification approaches based on linear systems theory are generally inappropriate for complex systems hence models that

are able to appropriately consider complex dynamical properties have to be employed in a predictive control algorithm This book first introduces some modeling frameworks which can encompass the most frequently encountered complex dynamical phenomena and are practically applicable in the proposed predictive control approaches Furthermore unsupervised learning methods that can be used for complex system identification are treated Finally several useful predictive control algorithms for complex systems are proposed and their particular advantages and drawbacks are discussed The presented modeling identification and control approaches are complemented by illustrative examples The book is aimed towards researches and postgraduate students interested in modeling identification and control as well as towards control engineers needing practically usable advanced control methods for complex systems

Advances in Process Control with Real Applications Ch. Venkateswarlu, 2025-06-18 Advances in Process Control with Real Applications presents various advanced controllers including the formulation design and implementation of various advanced control strategies for a wide variety of processes These strategies include generalized predictive control with and without constraints linear and nonlinear model predictive control dynamic matrix control nonlinear control such as generic model control globally linearizing control and nonlinear internal model control optimal and optimizing control inferential control intelligent control based on fuzzy reasoning and neural networks and controllers based on stochastic and evolutionary optimization This book will be highly beneficial to students researchers and industry professionals working in process design process monitoring process systems engineering process operations and control and related areas Describes various advanced controllers for the control of complex nonlinear processes Provides the fundamentals algorithms approaches control strategies and implementation procedures systematically Highlights the significance and importance of advanced process control with many real applications

Artificial Intelligence in Real-time Control (AIRC-2000) I. J. Rudas, J. K. Tar, 2001 This Proceedings contains the papers presented at the 9th IFAC AIRC 2000 Symposium on Artificial Intelligence in Real Time Control 2000 held at Budapest Polytechnic Hungary on 2 4 October AIRC 2000 builds on the excellent reputation of previous meetings in the series for providing top quality papers in this important research field A positive development illustrated by this Proceedings is a new trend towards pragmatism in the research field Examples of this trend are an increase in the number of actual industrial applications support for more widespread use of new sophisticated technologies e g materials design further intertwining of artificial intelligence and control theory methods that reduces the reliance on blind faith still too often associated with AI methods Many things have changed since the first AIRC event in 1988 Two examples illustrate the change in the general attitude of the IFAC family in 1990 one of the major closing presentations of the IFAC World Congress warned the control community about the coming hordes of AI people In 1999 one of the plenary papers at the IFAC World Congress pointed out that the AI based methods form a natural extension of control theory to the class of non linear systems with incomplete information at least as far as the optimisation is concerned This contrast in attitudes shows how during the

past decade many AI people have embraced control theory and many control people have learned the basics of AI This Proceedings serves to continue this excellent dialogue by providing many quality papers which link both fields Fuzzy Systems Conference (FUZZ), 2000 IEEE Neural Networks Council, 2000-05 **Intelligent Control Systems and Signal Processing 2003** M. G. Ruano, António E. Ruano, Peter J. Fleming, 2003 KEY FEATURES The first IFAC conference and thus proceedings to be specifically devoted to this field Presents the findings of experts and practitioners from the major soft computing themes Provides an overview of the theory and applications of intelligent control systems and signal processing Intelligent control systems and signal processing 2003 contains the selection of papers presented at the IFAC International Conference on Intelligent Control systems and Signal Processing ICONS 2003 The conference was sponsored by the most important organizations in the field among them were the Institute of Electrical and Electronic Engineers IEEE and the Control Systems Society CSS This proceedings volume contains 98 papers with three separate reviewers having reviewed all papers Including six plenary lectures given by leading experts in the field 2005 IEEE International Symposium on Intelligent Control & 13th Mediterranean Conference on Control and Automation, 2005 *Journal of Fermentation and Bioengineering*, 1992 **International Journal of Applied Mathematics and Computer Science**, 2004 **Modeling and Control of Biotechnical Processes 1992, (2nd IFAC Symposium) and Computer Applications in Fermentation Technology (5th International Conference)** Mohammed Nazmul Karim, G. Stephanopoulos, 1992 Hardbound This volume provides the state of the art findings of control theory and applications of biotechnical processes Topics covered include neural networks and their applications modeling identification AI and expert systems Index to Theses with Abstracts Accepted for Higher Degrees by the Universities of Great Britain and Ireland and the Council for National Academic Awards, 2004 Theses on any subject submitted by the academic libraries in the UK and Ireland Process Dynamics and Control Brian Roffel, Ben Betlem, 2006 Offering a different approach to other textbooks in the area this text is a comprehensive introduction to the subject divided into three broad parts building physical models developing empirical models and developing process control solutions *Intelligent Components and Instruments for Control Applications 1992* A. Ollero, E. F. Camacho, 1993 Intelligent control is an emergent field involving the development of new control techniques such as reasoning learning and perception and has a great impact on a number of applications including robotics and process control The symposium brought together control systems specialists equipment manufacturers and end users to evaluate techniques components and instruments for intelligent control The selected papers in this volume cover intelligent control techniques actuators sensors image processing computer vision software and communications Papers relating to applications such as robotics power and process control manufacturing aerospace and traffic control are also included **Journal of the Bulgarian Academy of Sciences** Българска академия на науките, 2005 **Proceedings of the Thirteenth National Conference on Artificial Intelligence and the Eighth Innovative Applications of Artificial Intelligence**

Conference American Association for Artificial Intelligence, 1996 AAAI proceedings describe innovative concepts techniques perspectives and observations that present promising research directions in artificial intelligence August 4-8 1996 Portland Oregon AAAI 96 provides a broad forum for information exchange and interaction among researchers working in different subdisciplines in different research paradigms and in different stages of research in artificial intelligence Topics cover principles underlying cognition perception and action design application and evaluation of AI algorithms and systems architectures and frameworks for classes of AI systems and analysis of tasks and domains in which intelligent systems perform Included are contributions that describe theoretical empirical or experimental results represent areas of AI that may have been underrepresented in recent conferences present promising new research concepts techniques or perspectives or discuss issues that cross traditional subdisciplinary boundaries Two volume set Distributed for the AAAI Press **The Engineering Index Annual** , 1994 Since its creation in 1884 Engineering Index has covered virtually every major engineering innovation from around the world It serves as the historical record of virtually every major engineering innovation of the 20th century Recent content is a vital resource for current awareness new production information technological forecasting and competitive intelligence The world's most comprehensive interdisciplinary engineering database Engineering Index contains over 10.7 million records Each year over 500,000 new abstracts are added from over 5,000 scholarly journals trade magazines and conference proceedings Coverage spans over 175 engineering disciplines from over 80 countries Updated weekly **Current Opinion in Biotechnology** , 1994 **Process and Chemical Engineering** , 1995

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