ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM MODEL WITH APPLICATION IN WASTEWATER SYSTEMS

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A project report submitted in partial fulfilment
of the requirements for the award of the degree of
Master of Engineering (Electrical – Mechatronics & Automatic Control)

Faculty of Electrical Engineering
University Technology Malaysia

JUNE 2014

"To my beloved Father, Mother, Wife and brothers"

ACKNOWLEDGEMENT

First of all, gratefulness of thanks to our creator, "ALLAH" for this continuous blessing, which make this work neither the first nor the last.

I would like to express my thanks and gratitude to my supervisor "Dr. NORHALIZA ABDUL WAHAB". She gave me this opportunity to do project under her supervision.

Especially, I would like to send my deep appreciations to my family who brought me up with love and completely support during my study.

ABSTRACT

Activated Sludge Process (ASP) is a highly complex and non-linear biological system; therefore, traditional mathematical modelling of this treatment process has remained a challenge. To improve treatment efficiency, quality of the effluent released into the receiving water body, find simple and easy model that can help the operator to predict the performance of the plant. Moreover, to take cost-effective and timely remedial actions that would ensure consistent treatment efficiency that meeting discharges consents. Therefore, this work highlights one of the techniques that have proved a great success in many scientific problems and applications. Adaptive Neuro-Fuzzy Inference System (**ANFIS**) has proven to be efficient, reliable and flexible. This work focus on the general concept and characteristics of adaptive neuro fuzzy inference system and its application in nonlinear and dynamic systems. Moreover, this work present MANFIS which is the extended of adaptive neuro fuzzy inference system (ANFIS). The proposed MANFIS is used in this project to make identification of four nonlinear outputs in the ASP: biomass, recycled biomass, dissolved oxygen and substrate. The last part of this work focuses on controller design – ANFIS inverse controller and model predictive control (MPC) that are used to compare the ability of these two techniques in dealing with nonlinear and complex systems and to predict and control the concentration of the two outputs, substrate and dissolved oxygen.

ABSTRAK

Proses Enapcemar Teraktif (ASP) adalah salah satu sistem biologi tidak linear yang sangat kompleks. Oleh itu, pemodelan matematik tradisional dalam proses rawatan ini masih dipersoalkan. Objektif kerja ini adalah untuk mencari model yang boleh membantu pengendali untuk meramalkan prestasi kilang supaya pengambilan tindakan pemulihan yang kos efektif dan tepat pada masanya. Ia adalah untuk memastikan keberkesanan rawatan yang konsisten dan memenuhi persetujuan pelepasan. Lebih jauh lagi, untuk meningkatkan kecekapan rawatan yang berkualiti and cecair yang dilepaskan ke dalam badan air adalah diterima. Oleh itu, kerja ini telah mengetengahkan salah satu teknik yang telah dibuktikan dengan kejayaan yang besar dalam banyak masalah saintifik dan aplikasi. Adaptive Sistem Inferens Neuro-Fuzzy (ANFIS) telah terbukti dengan kecekapan, mempercayakan dan fleksibel. Kerja ini menfokuskan konsep umum dan ciri-ciri penyesuaian neuro sistem inferens fuzzy serta aplikasinya dalam sistem tidak linear dan dinamik. Selain itu, kerja ini MANFIS merupakan lanjutan penyesuaian neuro sistem inferens fuzzy (ANFIS). MANFIS yang dicadangkan akan digunakan dalam projek ini untuk megenalkan empat output tidak linear dalam ASP: biomass, biomass dikitar semula, oksigen terlarut dan substrat. Bahagian terakhir kerja ini adalah memberi tumpuan kepada reka bentuk bagi pengawalan ANFIS songsang dan model kawalan ramalan (MPC) yang digunakan untuk membandingkan keupayaan antara kedua-dua teknik dalam menangani sistem tidak linear dan kompleks serta meramalkan dan mengawal kepekatan kedua-dua hasil, substrat dan oksigen terlarut.

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LIST OF SYMBOLS

X(t)	-	Biomass
X_r(t)	-	recycled biomass
$S(t)$	-	Substrate
$C(t)$	-	dissolved oxygen concentration
$D(t)$	-	Dilution rate
$W(t)$	-	air flow
K_{la}	-	Oxygen transfer rate coefficient
R	-	ratios of recycled to influent
β	-	waste flow to the influent flow rate
C_s(t)	-	state feedback gain matrix
C_{IN}	-	dissolved oxygen in feed system
S_{IN}	-	substrate concentration in the feed steam

LIST OF ABBREAVIATIONS

ANFIS	-	ADAPTIVE NEURO FUZZY INFERENCE SYSTEM
ANN	-	ARTIFICIAL NEURAL NETWORK
ASM1	-	ACTIVATED SLUDGE MODEL 1
ASP	-	ACTIVATED SLUDGE PROCESS
BOD	-	BIOCHEMICAL OXYGEN DEMAND
BP	-	BACKPROPAGATION
CANFIS	-	COACTIVE ADAPTIVE NEURO FUZZY INFERENCE SYSTEM
DO	-	DISSOLVED OXYGEN
FFNN	-	FEED FORWARD NEURAL NETWORK
FLS	-	FUZZY LOGIC SYSTEM
GSA	-	GRAVITATIONAL SEARCH ALGORITHM
GUI	-	GRAPHICAL USER INTERFACE
IAWQ	-	INTERNATIONAL ASSOCIATION ON WATER QUALITY
KSOM	-	KOHONEN SELF-ORGANIZING MAP
LSE	-	LEAST SQUARES ESTIMATORS
MANFIS	-	MULTIPLE ADAPTIVE NEURO FUZZY INFERENCE SYSTEM
MIMO	-	MULTI INPUT MULTI OUTPUT
MISO	-	MULTI INPUT SINGLE OUTPUT
MPC	-	MODEL PREDICTIVE CONTROL
NNs	-	NEURAL NETWORKS
RMSE	-	ROOT MEAN SQUARE ERROR
RNN	-	RECURRENT NEURAL NETWORK
SISI	-	SINGLE INPUT SINGLE OUTPUT

SS	-	SUBSTRATE
WAS	-	Waste activated sludge
WWTP	-	WASTEWATER TREATMENT PROCESS

CHAPTER 1

INTRODUCTION

1.1 Background of the Project

The main aim of the project is to provide reliable, efficient and simplified and easy to use modeling approach and appropriate control of an active sludge wastewater treatment process**.** One of the best techniques that have proved a great success in many scientific problems and applications is a neuro-fuzzy inference system. Adaptive neuro-fuzzy inference system (ANFIS) is candidate to deal with complex and nonlinear systems such as wastewater treatment process. So it has proven to be efficient, reliable and flexible for this task.

1.2 Problem Statement

The problem of the project is to design adaptive neuro- fuzzy inference system to model multi inputs multi outputs (MIMO) systems. For neuro-fuzzy modelling, adaptive neuro-fuzzy inference system (ANFIS) is used but, ANFIS itself only suitable for single output system. Therefore, for a system with multiple outputs, ANFIS are placed in parallel side by side to produce a Multi ANFIS (MANFIS). Since a MIMO fuzzy system can always be separated into a group of multi input-single output (MISO) fuzzy system, therefore, we can design MISO ANFIS controller individually, and then combine them into a MIMO ANFIS controller.

1.3 Objective of the Research

1. To study the characteristic of MIMO ANFIS.
2. Develop Multiple Adaptive Neuro-Fuzzy Inference System (MANFIS) for modeling ASP.
3. Design (ANFIS) controller based on direct inverse model using ANFIS inverse controller in order to control dissolved oxygen and substrate concentration.
4. Design MPC controller and discuss the results for both controllers.

1.4 Scope of the Project

The scope of the project will focus on modelling the secondary treatment in wastewater treatment plants activated sludge process (ASP), Activated Sludge Model No.1 (ASM1) from the International Association on Water Quality (IAWQ) task group will be utilized, in general the following steps will clarify the scope of the project:-

1. A brief introduction about wastewater treatment process, especially the secondary treatment process stage
2. Use matlab to build the activated sludge wastewater treatments using Activated Sludge Model No.1 (ASM1) and simulate the system.

3. A brief introduction to the principles of Adaptive Neuro-Fuzzy Inference System (ANFIS), which will used to model the system.
4. Use MANFIS the extended of ANFIS for modeling MIMO system.
5. Controller Design for MIMO system by using the ANFIS inverse controller and MPC controller.
6. Analyze and compare the results for both controllers.

REFERENCES

[1] Gleick, P. H. (1996). Water resources. *Encyclopedia of climate and weather*, *2*, 817-823.

[2] Metcalf, E. (2003). Inc., Wastewater Engineering, Treatment and Reuse. *New York: McGraw-Hill*.

[3] Spellman, F. R. (2003). Handbook of Water and Wastewater Treatment Plant Operation. Lewise publishers, USA.

[4] Capodaglio, A.G. (1994). Evaluation of Modelling Techniques for Wastewater Treatment Plant Automation. Water Sci Tech 30 (2) pp. 149–156.

[5] Esteves, S. (2002). Monitoring and Control of Biological Textile Wastewater Treatment Using Artificial Neural Networks. PhD thesis, university of Lamorgan, UK.

[6] Mamdani, E. H. and Assilian, S. (1975). An experiment in linguistic synthesis with a fuzzy logic controller. *International journal of man-machine studies*, *7*(1), 1-13.

[7] Zadeh, L. A. (1965). Fuzzy sets. Information and control, 8(3), 338-353.

[8] Tsai, Y. P., Ouyang, C. F., Wu, M. Y. and Chiang, W. L. (1993). Fuzzy control of a dynamic activated sludge process for the forecast and control of effluent suspended solid concentration. *Water Science & Technology*, *28*(11-12), 355-367.

[9] Müller, A., Marsili-Libelli, S., Aivasidis, A., Lloyd, T., Kroner, S. and Wandrey, C. (1997). Fuzzy control of disturbances in a wastewater treatment process. *Water Research*, *31*(12), 3157-3167.

[10] Ferrer, J., Rodrigo, M. A., Seco, A. and Penya-Roja, J. M. (1998). Energy saving in the aeration process by fuzzy logic control. *Water science and technology*, *38*(3), 209-217.

[11] Manesis, S. A., Sapidis, D. J. and King, R. E. (1998). Intelligent control of wastewater treatment plants. *Artificial Intelligence in Engineering*, *12*(3), 275-281.

[12] Tong, R. M., Beck, M. B. and Latten, A. (1980). Fuzzy control of the activated sludge wastewater treatment process. *Automatica*, *16*(6), 695-701.

[13] Czogaa, E. and Rawlik, T. (1989). Modelling of a fuzzy controller with application to the control of biological processes. *Fuzzy Sets and Systems*, *31*(1), 13-22.

[14] Yu, C., Cao, Z. and Kandel, A. (1990). Application of fuzzy reasoning to the control of an activated sludge plant. *Fuzzy Sets and Systems, 38* (1), 1-14.

[15] Meyer, U. and Ppel, H. (2003). Fuzzy-control for improved nitrogen removal and energy saving in WWT-plants with pre - denitrification. *Water Science and Technology*, *47*(11), 69-76.

[16] Vera, G., Sanchez, E. N., Béteau, J. F. and Cadet, C. (2003). Intelligent control of an activated sludge wastewater treatment plant. In *American Control Conference ACC03*.

[17] Traoré, A., Grieu, S., Thiery, F., Polit, M. and Colprim, J. (2006). Control of sludge height in a secondary settler using fuzzy algorithms. *Computers and chemical engineering*, *30*(8), 1235-1242.

[18] Jang, J. S. (1993). ANFIS: adaptive-network-based fuzzy inference system.*Systems, Man and Cybernetics, IEEE Transactions on*, *23*(3), 665-685.

[19] De Vos, N. J. and Rientjes, T. H. M. (2005). Constraints of artificial neural networks for rainfall-runoff modelling: trade-offs in hydrological state representation and model evaluation. *Hydrology and Earth System Sciences Discussions*, *2*(1).

[20] Hamed, M. M., Khalafallah, M. G. and Hassanien, E. A. (2004). Prediction of wastewater treatment plant performance using artificial neural networks.*Environmental Modelling and Software*, *19*(10), 919-928.

[21] Raduly, B., Gernaey, K. V., Capodaglio, A. G., Mikkelsen, P. S. and Henze, M. (2007). Artificial neural networks for rapid WWTP performance evaluation: Methodology and case study. *Environmental Modelling and Software*, *22*(8), 1208-1216.

[22] Chen, J. C., Chang, N. B. and Shieh, W. K. (2003). Assessing wastewater reclamation potential by neural network model. *Engineering Applications of Artificial Intelligence*, *16*(2), 149-157.

[23] Du, Y. G., Tyagi, R. D. and Bhamidimarri, R. (1999). Use of fuzzy neural-net model for rule generation of activated sludge process. *Process Biochemistry*, 35(1), 77-83.

[24] Jang, J. S. R. and Gulley, N. (1997). MATLAB/Fuzzy Logic Toolbox, Math Works. *Inc. Natick, MA.*

[25] Sugeno, M., and Kang, G. T. (1988). Structure identification of fuzzy model. *Fuzzy sets and systems*, *28*(1), 15-33.

[26] Long, L., Fei, L., You, Z. L., Tao, Y. H. and Yuge, X. (2011). Predicting wastewater sludge recycles performance based on fuzzy neural network. In *Networking, Sensing and Control (ICNSC), 2011 IEEE International Conference on* (pp. 266-269). IEEE.

[27] Areerachakul, S. (2012). Comparison of ANFIS and ANN for estimation of biochemical oxygen demand parameter in surface water. *Int. J. Chem. Biolog. Eng*, *6*, 286-290.

[28] Gaya, M. S., Wahab, N. A., Sam, Y. M., Razali, M. C. and Samsudin, S. I. (2012, November). Neuro-fuzzy modelling of wastewater treatment system. *In Control System, Computing and Engineering (ICCSCE),* 2012 IEEE International Conference on (pp. 250-253). IEEE.

[29] Gaya, M. S., Wahab, N. A., Sam, Y. M., Anuar, A. N. and Samsuddin, S. I. (2013). ANFIS Modelling of Carbon Removal in Domestic Wastewater Treatment Plant. *Applied Mechanics and Materials*, *372*, 597-601.

[30] Rustum, R. (2009). Modelling activated sludge wastewater treatment plants using artificial intelligence techniques (fuzzy logic and neural networks) (Doctoral dissertation, Heriot-Watt University).

[31] Rustum, R., Adeloye, A. and Simala, A. (2007). Kohonen self-organising map (KSOM) extracted features for enhancing MLP-ANN prediction models of BOD5.*IAHS-AISH publication,* 181-187.

[32] Miller, A. (2006). An Investigation into Fuzzy Logic for use in Inhabited Intelligent Environments in particular the use of ANFIS with a rich data set.

[33] Jang, J. S. R. and Sun, C. T. (1996). *Neuro-fuzzy and soft computing: a computational approach to learning and machine intelligence*. Prentice-Hall, Inc.

[34] Ghaffari, A., Khodayari, A., Alimardani, F. and Sadati, H. (2012). Manfis-based overtaking maneuver modeling and prediction of a driver-vehicle-unit in real traffic flow. In *Vehicular Electronics and Safety (ICVES), 2012 IEEE International Conference on* (pp. 387-392). IEEE.

[35] Benmiloud, T. (2010). Multi-output adaptive neuro-fuzzy inference system. In *WSEAS INTERNATIONAL CONFERENCE ON NEURAL NETWORKS* (Vol. 11, pp. 94-98).

[36] Osman, M. K., Mashor, M. and Arshad, M. (2004). Multi-View Technique For 3-D Robotic Object Recognition System Using Neuro-Fuzzy Method.

[37] M Khusairi, O., Mohd Yusoff, M., M Rizal, A. and Zuraidi, S. (2009). 3D Object Recognition Using MANFIS Network with Orthogonal and Non-Orthogonal Moments. Widrow, B., and Walach, E. (2008). *Adaptive Inverse Control, Reissue Edition: A Signal Processing Approach*. John Wiley and Sons.

[38] Nejjari, F., Dahhou, B., Benhammou, A. and Roux, G. (1999). Non-linear multivariable adaptive control of an activated sludge wastewater treatment process. *International Journal of Adaptive Control and Signal Processing*, *13*(5), 347-365.

[39] Ling, T. G., Rahmat, M. F. and Husain, A. R. (2013). ANFIS Modeling and Direct ANFIS Inverse Control of an Electro-Hydraulic Actuator System. *In Industrial Electronics and Applications (ICIEA), 2013 8th IEEE Conference on* (pp. 370-375). IEEE.

[40] Caraman, S., Sbarciog, M. and Barbu, M. (2007). Predictive Control of a Wastewater Treatment Process. *International Journal of Computers, Communications and Control*, *2*(2).

[41] Silva, C. H. F., Henrique, H. M. and Oliveira-Lopes, L. C. (2012). Experimental Application of Predictive Controllers. *Journal of Control Science and Engineering*, *2012*, 4.

[42] Van den Boom, T. J. and Backx, T. C. P. M. (2010). Model predictive control. *Dutch Institute of Systems and Control, Lecture Notes*.