NEURAL NETWORK MODEL PREDICTIVE CONTROL OF A ULTRA HIGH TEMPERATURE MILK TREATMENT PLANT

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ABSTRACT

This thesis reports the development of a Model Predictive Control system for a Ultra High Temperature milk treatment pilot plant. This control system utilises an Artificial Neural Network model of the plant dynamics. The entire process was divided into two parts for modelling purposes. Separate models were trained; one for simulating the dynamics of the hot water heating loop and the second the dynamics of the heat exchanger circuit. The two sub-models, when concatenated, form a complete model of the plant referred to as a composite neural network model. The results of training and testing of the sub-models with various sets of plant data were presented.

Of all the possible combination of sub-models, the best trained and tested sub-models were concatenated to form the best composite network model, and the combination of worst sub-models to form worst composite network model. Two model predictive control (MPC) systems for the process were developed, one using the best composite network model for prediction purposes and to act as the plant, and the other using the worst composite model for prediction and best composite model as the plant.

Both the developed MPC systems were evaluated in terms of setpoint tracking and disturbance rejection. As a part of these performance tests, a PI (Proportional-Integral) control system of the UHT plant was developed in a simulated environment using the best composite neural network model to act as the plant. The responses of both the MPC control systems were studied and compared with the responses of the PI control system.

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CHAPTER ONE

INTRODUCTION

This chapter outlines the scope of the research work reported in this thesis. It briefly describes the usage of artificial neural networks in a model based control methodology which offers a great potential to enhance the control performance in complex multi-variable systems compared to the conventional Proportional-Integral-Derivative (PID) controllers.

Ultra high temperature (UHT) milk treatment plants are commonly used in the dairy industry for sterilisation of milk which demand a highly accurate and precise control to keep up the higher product quality. The inability of the conventional controllers being used by the existing UHT plants in giving better performance and also the *fouling* problem in the heat exchangers have been the motivation for this research work. This research work presents a specific application of neural networks in a model predictive control scheme for an UHT plant.

The section 1.1 of this chapter presents the scope of this research and sections 1.2 and 1.3 briefly outlines the development of neural network UHT plant model and its usage in the model predictive control system development. The merits and demerits of the neural network model based control system design over the classical controller designs are also presented. The section 1.4 of this chapter provides an outline of all the subsequent chapters presented in this chapter.

1.1 SCOPE OF THIS THESIS

The design of control systems require both steady state and dynamic information about the process. By providing a model of the actual system using the input-output process data to be used in the design and simulation of the system, system representation, modelling and identification proved to be the most vital in process engineering.

The insufficient control performance of the conventional PID controllers in terms of accuracy and preciseness in complex non-linear systems forced the control engineering field to come up with highly accurate and intelligent controllers. This requirement lead the field to make use of computing for developing intelligent systems.

In the recent times, the use of artificial intelligence techniques for tackling many real world problems has increased significantly. These artificial intelligence techniques include neural networks, expert systems and fuzzy logic. The application of artificial neural networks in identifying highly non-linear dynamic system models and designing control strategies based on these models has been a promising advance in the control systems engineering field.

The UHT process is used for the sterilisation of milk so as to kill the bacteria by means of heating the milk to a high temperature and holding it at that temperature for a certain time and then cooling it. This sort of milk treatment process helps to keep the milk stored for longer time periods at room temperature compared to the pasteurised milk which can not last as long and needs to be kept refrigerated.

This work is based on a specific UHT plant at the New Zealand Dairy Research Institute, in Palmerston North. In this UHT process, the existing conventional control system was unable to cope with the requirement of accurate control for steady high temperature in the process for a short period of time. Apart from this, the *fouling* problem in the heat exchanger also lead to this research work for developing an intelligent and smart control system for UHT plant. The term *fouling* relates to a condition where the walls of the heat exchanger in a UHT plant became coated with a thick layer of milk fat globules over a period.

As UHT systems in general are expected to contain significant non-linearities due to the complex properties of milk, a model based control methodology seemed to be the best form of intelligent control and thus the research was carried out in developing an neural network based model predictive control system for the UHT process. The next sections briefly describes the system development and performance evaluation.

1.2 NEURAL NETWORK PLANT MODELLING

Basically, artificial neural networks were developed after an in-depth study of the human brain which has a parallel architecture of neurons. These artificial neural networks copy many of the biological features of the human brain which include their parallel processing capability.

For any process model design and development using artificial neural networks, first the process inputs to be manipulated and outputs which need to be measured and controlled have to be determined first. After designing the network with the desired number of past and present inputs and past outputs, and neural network topology the network has to be trained. The training has to be carried out using the past plant input and output data so that the neural network will learn the process.

The trained network model has to be tested for its ability to predict the output data using the input data which the model hasn't seen before. The performance of the model will be evaluated based on the error in predicting the unknown data.

After studying the UHT plant, it was decided to take the entire UHT process together for designing a single process model for neural network training. The data from various UHT plant runs was collected for training the network and in developing neural network models using different process runs. Developing a plant model which can cope with all the possible input and output constraints and can handle variations in the process lead to the idea of designing and developing the neural network models with different process runs.

1.3 MODEL BASED CONTROL USING NEURAL NETWORKS

The model based control strategy uses a dynamic model of the plant to provide efficient control of the system in a real time environment. In the past, this methodology proved to have the ability to cope with the process constraints and in handling non-linear processes. So the usage of the neural network model in developing a model predictive control scheme for the UHT process seemed to be a reasonable option in achieving the desired results which also became one of intelligent control system design.

The use of neural networks in model based control systems design offered a promising ability to enhance the performance of the control system as was proved before in quite a few process industries, especially in petro-chemical industries (Garcia *et al.*, 1989).

The performance of the developed model predictive control system which uses a neural network model of the UHT plant needs to be evaluated so as to prove its ability in comparison with the existing conventional PI control system. For this performance evaluation it was decided to evaluate the performance of the model predictive control system and the PI control system in a simulated environment. The next section presents an outline of the research work including a brief description of all the chapters in this thesis.

1.5 OUTLINE OF THIS THESIS

The six subsequent chapters in this thesis are

Chapter 2 Gives a background on the neural networks, classical PID control, Modern control strategies like model based control. Also compares the benefits of the modern control over classical control. Explains past research in successful development and implementation of model predictive control systems.

Chapter 3 Explains in detail about the single neural network model development of the UHT milk process. The development of two individual neural network sub-models, steam valve and heat exchanger models after dividing the UHT process. This chapter also explains the concatenation of the above two sub-models to form a composite neural network model to be used in the model predictive control system development.

Chapter 4 Explains the development of a model predictive control system for the UHT plant using the developed composite neural network model of the plant.

Chapter 5 Presents the training and testing results of the neural network models and the performance evaluation results of the developed model predictive control system compared to the PI control system. Also presents a comprehensive discussion of the above results.

Chapter 6 Conclusions of this research work and recommendations for any future work in this area.

Chapter 7 References and Bibliography

Chapter 8 Presents the software used in this work and the complete prediction error results of neural network models in the Appendices.