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Dynamic Modelling of a Falling-film Evaporator for Model Predictive Control

A thesis presented in partial fulfilment of the requirements
for the degree of Doctor of Philosophy in Technology
at Massey University

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Abstract

Fundamentally this thesis provides a study into dynamic modelling of a pilot-scale falling-film evaporator. Its main aim, however, is to research and demonstrate artificial neural network (ANN) modelling for model predictive control as applied to an evaporator system.

As a prerequisite to testing an advanced control strategy such as model predictive control one must have available a suitable dynamic simulation of the process. To this end the thesis initially presents the formulation of a dynamic model of the evaporator system developed from first-principles.

A novel approach to developing a dynamic ANN representation of a process is presented and applied to the evaporator. This approach incorporates prior knowledge of the system into the network topology to attain a model with a flexible, modular structure. A dynamic, recurrent training methodology is devised to enable the ANN model to predict over a future horizon of arbitrary length.

The performance of the modular ANN model is compared with a linear model of a similar form identified through conventional linear regression methods. It was found that the nonlinear ANN model and subsequent nonlinear MPC scheme exhibited no improvement in performance to that of their linear counterparts.

Errata

- p. 31 paragraph 4, line 1 should read: "...with an evaporation rate..."
- p. 42 paragraph 4, line 2 should read: "...shows how the energy..."
- p. 46 paragraph 1, line 1 should read: "... A_l is a function of L ..."
- p. 47 paragraph 7, line 2 should include: "... l_e/d ..." and not "... L_e/d ..."
- p. 83 paragraph 4, line 2 should read: "...by the model as a function of..."
- p. 104 paragraph 1, line 1 should read: "...then the neuron will turn on..."
- p. 105 paragraph 2, line 2 should read: "...are adapted it is said that..."
paragraph 3, line 2 should read: "...on opposite sides of a hyperplane..."
- p. 118 paragraph 3, line 5 should read: "...a number of times..."
- p. 157 paragraph 2, line 5 should read: "...foolhardy..."
- p. 166 paragraph 4, line 4 should read: "...was selected for study..."
- p. 168 paragraph 2, line 1 should read: "...of the effect requires four input variables..."
- p. 169 paragraph 8, line 2 should read: "...but this was considered to short..."
- p. 190 paragraph 1, line 3 should read: "...output of neuron 2 has an inverse..."
- p. 199 paragraph 2, line 7 should read: "...individual errors are not as good..."
- p. 231 paragraph 1, line 3 should read: "...occur at a time of 1 minute and eight minutes on the plots..."
- p. 234 Figure 8-6: in the legend the "PI-control" and "NN-MPC" labels have been interchanged.

Thesis Contribution

This thesis has made the following contributions:

Analytical modelling

1. The development of an analytically-derived, dynamic model of a falling-film evaporator pilot-plant which is an extension of earlier modelling work.

The major extensions to the evaporator model include:

- the re-formulating of the model for a feedforward configuration,
 - the deriving of equations for the preheater system,
 - the deriving of equations for the venturi condenser sub-systems, and
 - the inclusion of an additional product temperature state variable.
2. The combining of the analytical sub-models for three evaporation effects and the additional sub-systems to describe the complete evaporator system.
 3. The validation of the complete analytical model against data from the actual plant.

Artificial neural networks

4. The conception of a modular, artificial neural network modelling approach for the development of models to be used within a predictive control strategy.
5. The demonstration of neural network structure selection based upon prior knowledge of the system to create locally-connected, modular models.
6. The application of a dynamic, recurrent training methodology combining backpropagation through time and the Levenberg-Marquardt optimisation method to train the neural networks.
7. The comparison of a modular, artificial neural network model and an equivalent linear model identified through conventional regression techniques.

Model Predictive Control

8. The demonstration of the modular artificial neural network within a model predictive control strategy applied to the evaporator simulation.

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Thanks also to my family for all their support and encouragement, particularly my mother and father who have given me the opportunity to achieve what I have to date. I'd like to thank them for all their generosity to me during my university days.

I am extremely grateful to my wife Claire for all that she has been for me. I am very pleased that she was with me during my PhD 'journey' and I love her very much. Her unfailing support and continual belief in me has been an invaluable source of strength. This thesis truly belongs to her also.

Finally, I would like to thank God for everything he has provided me and enabled me to experience. He is the source of all good things. These last few years, although at times a struggle, have certainly been a 'good thing' – thank you.

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