

Developing a Model of an Intelligent Control Technique on a Manufacturing Batching Process

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Abstract

Complex control algorithms are applied to manufacturing systems for certain process requirements, according to product specifications. When implementing specific complex control algorithms, primary and secondary conditions affect each other, affecting the measuring and control processes. While complex control algorithms result in several benefits, problems associated with mathematical reasoning and time delays need to be considered for an intelligent decision-making control technique to optimise control of the manufacturing process. The research will derive a suitable control technique by means of an adaptive neuro-fuzzy inference system, to optimise the manufacturing process. The paper will discuss technical aspects, the experimental set-up and the design process. Completed research on industrial Siemens FuzzyControl++ design tool and current research on MatLab Fuzzy Logic Toolbox will form part of the discussion on the design process. The paper will conclude with a comparison of various analysis results in MatLab Fuzzy Logic Toolbox.

Keywords: *Decision-making, Manufacturing, Intelligent Control*

1 Introduction

Conventional control systems express control solutions by means of control expressions, usually mathematically based. In order to completely express the control solution, a vast amount of data is required. This is either difficult or virtually impossible to obtain. In contrast, intelligent decision making solutions require far less plant data and mathematical expression. This reduces development time proportionally. The research is based on a multi-variable manufacturing plant, within which a fuzzy logic controller is used to maintain the blend chest level. The control algorithm is tested in a simulated environment. In the Fuzzy Control framework two types of human knowledge are specified: [16,21,23]

- Plant knowledge: Fuzzy IF-THEN rules that describe the behaviour of the plant, e.g. “IF the flow control valve opens, THEN the temperature of the process medium will increase”, where ‘open’ and ‘increase’ are characterized by Fuzzy sets.
- Control knowledge: Fuzzy Control rules that state in which situations what control actions should be taken, e.g. “IF the process medium temperature decreases, THEN the output of the controller

should increase”, where ‘decrease’ and ‘increase’ are characterized by Fuzzy sets.

The control algorithm in this multi variable plant is based on the combined indirect/direct adaptive neuro-fuzzy inference system.

2 Experimental Setup

The main problem in maintaining a consistent blend chest level and supply pressure is nullifying the effect of outside influences. Both the variables depend primarily on the amount of fluid entering the blend chest and the demand required by the manufacturing plant [4,5]. The research is based on the regulation of correct amount of supply through PV1a operating from 0% to 50% of the control signal and PV1b operating from 50% to 100% of the control signal. When the supply and demand conditions vary the desired blend chest level and supply pressure can be greatly affected, and it becomes necessary to quickly readjust them to meet process conditions to maintain quality and logistical requirements. The level in the Blend Chest is measured by LT1 (level-transmitter 1) and the pressure on the delivery side of the pump is

measured by PT1 (pressure-transmitter). The supply to the manufacturing plant is regulated at two points

via PV1a (pressure-valve a) and PV1b (pressure-valve b).

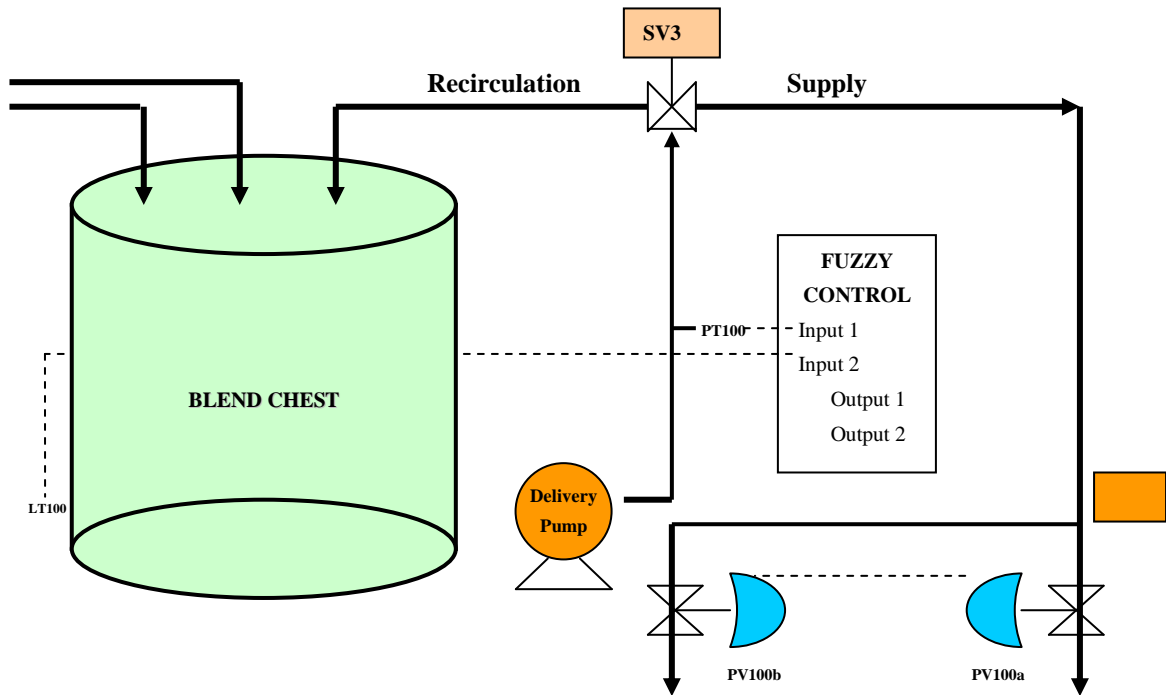


Figure 1: Process plant layout configured in combined split-range and fuzzy control

Split-range control benefits this manufacturing process by integrating the two final correcting elements, to maintain a consistent supply to the manufacturing plant as per process requirements [4]. However, there are limitations in any mathematically based control system due to the algorithm relying on mathematical calculations on deviations from the desired value. A 2-input, 2-output fuzzy controller is tested as indicated in Figure 1.

3 FuzzyControl++ Design Tool

Two inputs, process pressure and blend chest level, and two outputs applied to pressure valves were defined. After naming the inputs and outputs the membership functions had to be defined, for each input and output. The trapezoid form was used for the inputs, in order to increase the number of corner points, for clear distinction of one function from the other. The outputs were inserted as singletons. The rules were then edited in the inference engine, in either the rule table or rule matrix form [15,19,24].

In order for the desired process pressure to be maintained, it was dependent on certain plant and

control variables. These variables had to be analysed at different values, within a specified band, in order to maintain the process pressure at the desired value. The membership functions (procedural knowledge) for both, the inputs and outputs were derived from the following plant variables, for the specified band:

- Process pressure
- Blend chest level
- Position of pressure control valves a and b, configured in split-range

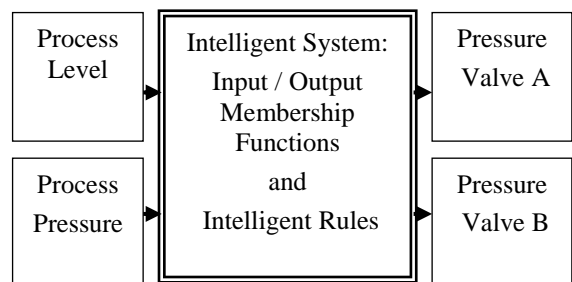


Figure 2: Overview of Intelligent Strategy

The rules (declarative knowledge) for the rule-based system were derived from the following control variables, for the specified band:

- Data communication signals from the process pressure and blend chest level transmitters
- Data communication signals to pressure control valves a and b

Figure 2 represents the knowledge engineering process in a generic form [9,16,19].

Figure 3 represents the edited input membership functions in trapezoid form, for only process pressure (PT100) as configured in Siemens FuzzyControl++ design tool. Table 1 represents the actual corner points of each membership function. This facilitates fuzzification of a crisp value by scaling and mapping the input's domain, a linguistic variable, into an internal computer code. The second input, blend chest level (LT100) was configured in the same way as discussed above [13,18,22].

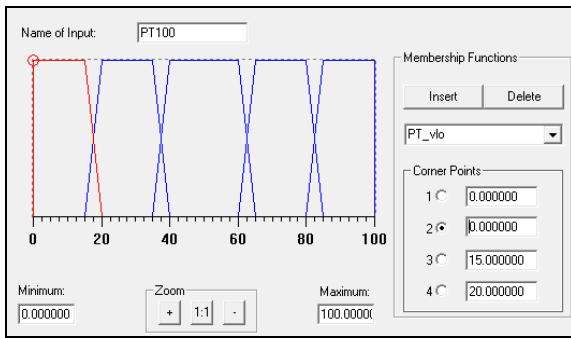


Figure 3: Edited Pressure (Graphical)

Table 1: Edited Pressure (Actual values)

MF	PT 1	PT 2	PT 3	PT 4
PT_vlo	0.0	0.0	15.0	20.0
PT_lo	15.0	20.0	35.0	40.0
PT_med	35.0	40.0	60.0	65.0
PT_hi	60.0	65.0	80.0	85.0
PT_vhi	80.0	85.0	100.0	100.0

Figure 4 represents the edited output membership functions in singleton form, for only process pressure valve a (PV100a), as configured in Siemens FuzzyControl++ design tool. Table 2 represents the actual values of each membership function. This facilitates de-fuzzification of the internal computer code to a crisp value by scaling and mapping the

output's domain. The second output, process pressure valve b (PV100b), was configured in the same way as discussed above. It will be noted that valve a, as indicated, operates between 0.00% to 50.00% and valve b operates between 50% and 100%, due to the split-range principle. In the absence of a firing rule the output is maintained at the last value [6,17,25].

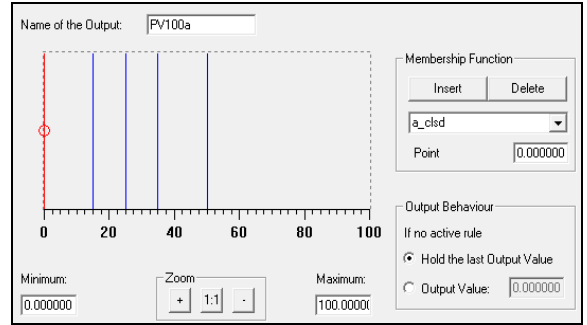


Figure 4: Edited Pressure Valve a (Graphical)

Table 2: Edited Pressure Valve a (Actual Values)

MF	VALUE
a_clsd	0.00
a_sclsd	15.00
a_half	25.00
a_sopn	35.00
a_opn	50.00

Figure 5 represents the rules that govern pressure valve a in the knowledge engineering process of the inference stage. The facts and rules (declarative knowledge) are represented separately from decision-making algorithms (procedural knowledge). From figure 5 the rule numbers are read from left to right in ascending order, e.g. rule 5 states that IF PT100=PT_vhi and LT100=LT_lo, THEN PV100a=a_sclsd.

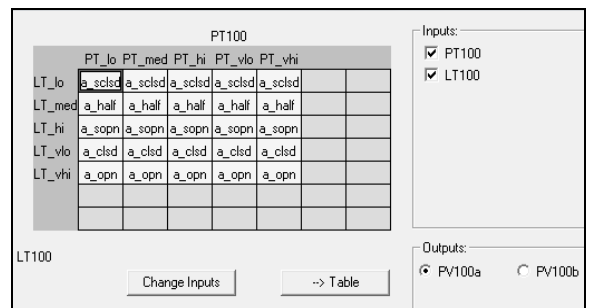


Figure 5: 25 Rules for Valve a

4 MatLab Design Tool

The combined indirect/direct ANFIS (Adaptive Neuro-Fuzzy Inference System) is derived from plant and control knowledge by a Sugeno, or Takagi-Sugeno-Kang method. The Sugeno is used instead of the Mamdani, as it generates either linear or constant, in keeping with on-line system design as shown in Figure 6 [1,12,14].

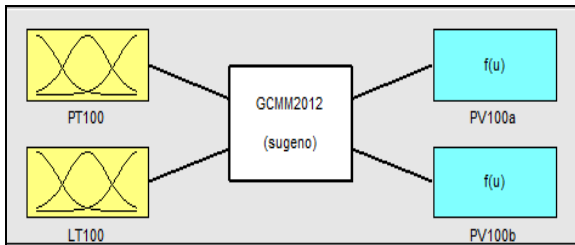


Figure 6: Sugeno Fuzzy Model

A typical rule in a Sugeno fuzzy model is as follows:-
If Input 1 = x and Input 2 = y, then Output is: z = ax + by + c

For a zero-order Sugeno model, the output level z is a constant (a=b=0).

The output level z_i of each rule is weighted by the firing strength w_i of the rule, e.g. for an AND rule with Input 1 = x and Input 2 = y, the firing strength is:

$$W_i = \text{AndMethod} \{F_1(x), F_2(y)\}$$

where $F_{1,2}$ are the membership functions for Inputs 1 and 2. The final output of the system is the weighted average of all rule outputs, computed as :

$$\text{Final Output} = \frac{\sum_{i=1}^N w_i z_i}{\sum_{i=1}^N w_i}$$

The membership function parameters are tuned using a back-propagation algorithm alone or combined least squares method, allowing the FIS to learn from the modelled data. The ANFIS model structure, as shown in Figure 7, represents the desired configured system. The first output functions from 0% to 50% (not indicated) and the second output from 50% to 100% [2,8,20].

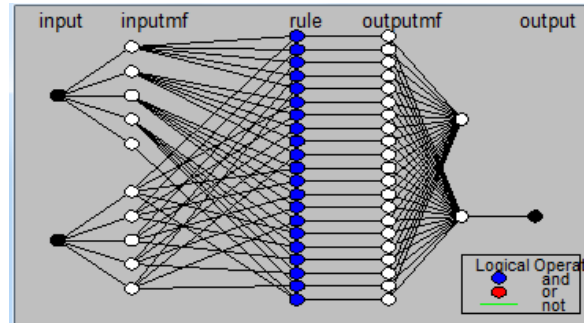


Figure 7: ANFIS Structure

It comprises the following:

- Two inputs, Level and Pressure, each with five membership functions were derived
- The derived rule base comprises 21 rules that are applied to 21 output membership functions in an AND logic operation;
- The output membership functions are aggregated to connect to a single output.

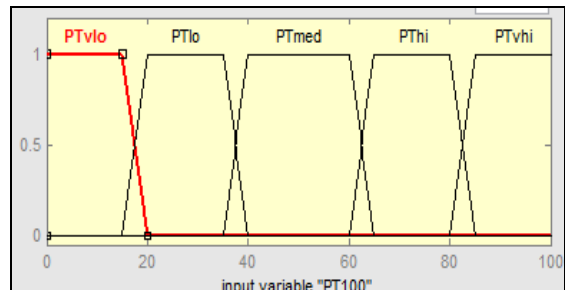


Figure 8: Membership Functions for Input 1

Figure 8 represents the membership functions of input 1, Process Pressure. The assigned membership functions, in trapezoid format, in MatLab Fuzzy Logic Toolbox are the same as designed in Siemens FuzzyControl++, indicated in Table 1. For analysis purposes the four corner points for “PTvlo” can be seen as 0.0, 0.0, 15.0 and 20. The remaining four membership functions can be analysed in the same way [3,9,11].

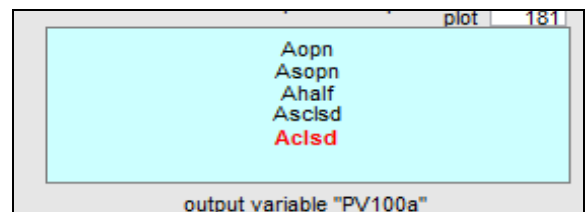


Figure 9: Membership Functions for Input 1

Figure 9 represents the membership functions of output 1, Pressure Valve A. The assigned membership functions, as singletons, in MatLab Fuzzy Logic Toolbox are the same as designed in Siemens FuzzyControl++, indicated in Table 2. For analysis purposes the first membership function “Aclsd” can be seen as 0.0. Since PV100a functions from 0% to 50% of the control signal, the remaining membership functions were Asclsd (15.0), Ahalf (25.0), Asopn (35.0) and Aopn (50.0) respectively.

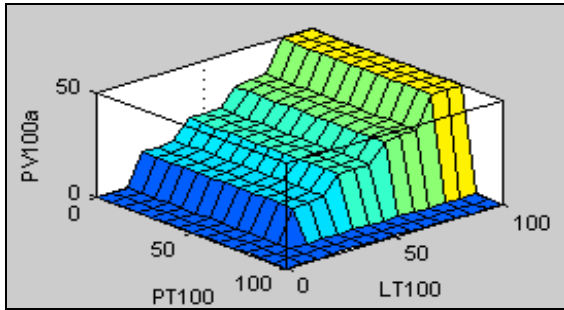


Figure 10: Surface View Plot

Figures 10 represent the surface view of the designed model to examine the response of the output, “PV100a”, versus the two inputs of the FIS. Both inputs “PT100” on the X-axis and “LT100” on the Y-axis appear against “PV100a” on the Z-axis. By analysing one of the response points of the output, it can be seen that if “PT100” is 50.0 and “LT100” is 50.0, then “PV100a” is 50.0. These values can be verified against Figures 11, Rule Editor, and 12, Rule Viewer, where Rule 13 states that IF PT100 = PTmed (any value between the trapezoid points of 35.0-40.0-60.0-65.0) AND LT100 = LTmed (any value between the trapezoid points of 35.0-40.0-60.0-65.0) THEN PV100a = Ahalf (singleton value of 25.0 that is 50% of its range value), PV100b = Bhalf (singleton value of 75.0 that is 50% of its range value). The analysis for PV100b can be verified in the same way [7,10].

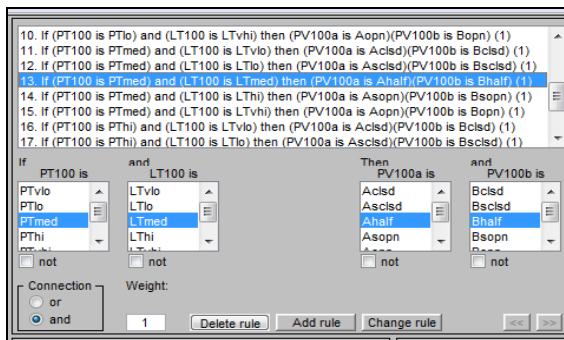


Figure 11: Rule Editor

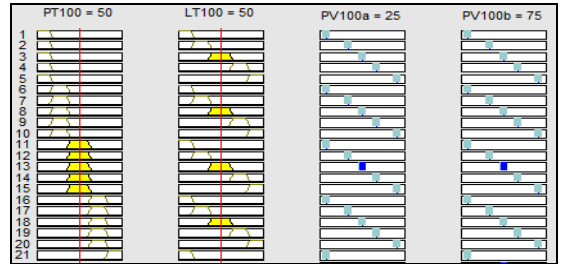


Figure 12: Rule Viewer

5 Conclusions

There are various soft computing techniques available to solve the research problem. The author has chosen specific hardware and software in view of progression in the research. The MatLab model will be interfaced to the plant via Advantech, for real-time analysis. Siemens technology is used as all field components are based on the same technology, to avoid interface conflict.

From Figures 10, 11, 12 the configured input and output membership functions can be verified as correct, for real-time implementation, in Siemens FuzzyControl++. In Figure 11, Fuzzy Rule 13 states that IF PT100=PTmed AND LT100=LTmed, THEN PV100a=Ahalf AND PV100b=Bhalf. Analysing Figure 12, Fuzzy Rule 13 indicates in two-dimensional analysis that IF PT100=50% AND LT100=50%, THEN PV100a=25% AND PV100b=75%. At this point the graphical and numerical values verified that the assigned rules are valid, for these process conditions. Analysing Figure 10, 50% PT100 versus 50% LT100 indicates clearly that PV100a is 50%. The scale of PV100a is calibrated for 0% to 50%, as indicated in Figure 10, and PV100b operates between 50% to 100%, as discussed in Section 2, in split-range configuration, to meet process requirements. A cross-reference to Figures 8 and 9 verifies the input membership functions as trapezoids and output membership functions according to the design process. This final analysis verifies that the fuzzification-to-fuzzy rules-to-defuzzification algorithm of the intelligent control strategy in a simulation environment can be tested in real-time.

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