



## A Discrete Model Approach to ARGESIM Benchmark C9 'Fuzzy Control of a Two-Tank System' with MATLAB, Simulink and Fuzzy Control Toolbox

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**Simulator:** This comparison solution has been accomplished with MATLAB, Simulink, and with MATLAB's Fuzzy Toolbox. MATLAB is an environment for numerical computations and a high level programming language. Simulink is a tool, integrated into MATLAB, which allows to model a dynamic system by graphical blocks and to simulate its real world behaviour. The Fuzzy Toolbox supports design of fuzzy control to be used in MATLAB and Simulink (WWW.MATHWORKS.COM).

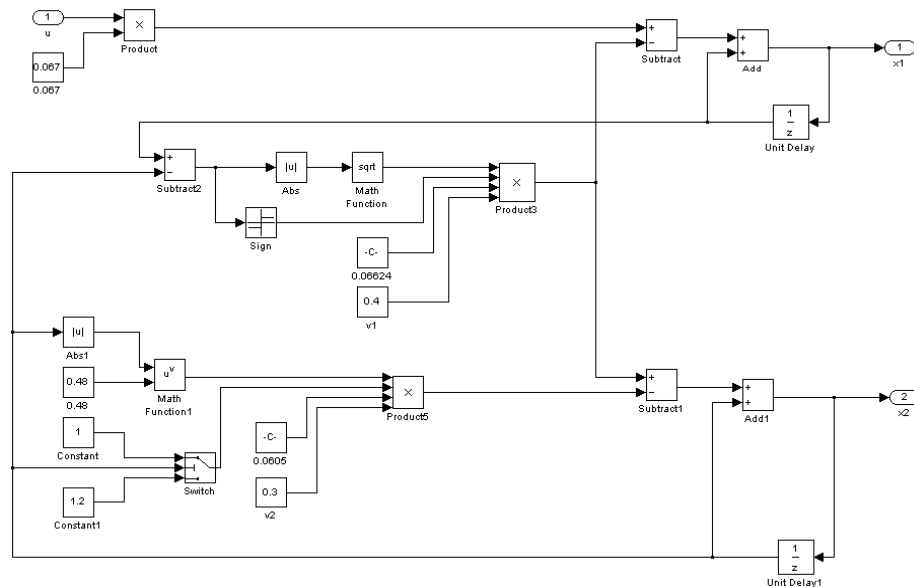


Figure 2: Submodel of the two tank system - explicit discrete model.

**Modelling.** The model is composed in Simulink in a modular manner (Figure 1): submodels for the fuzzy controller (input  $x_1$ ,  $ex_2$ ; output  $u$ ) and for the plant (input  $u$ ; output  $x_1$ ,  $x_2$ ), reference as constant input (output  $x_{2s}$ ), and sum block for deviation  $ex_2$  (input  $x_{2s}$ ,  $x_2$ ; output  $ex_2$ ).

The two-tank system is implemented with standard Simulink blocks (Figure 2) as explicit discrete system: instead of integrator blocks for  $x_1$  and  $x_2$ , discrete equations are implemented with unit delay blocks directly fed back. In principle, the ODEs are solved by Euler algorithm with stepsize 1 (equals control cycle time).

The *Fuzzy Logic Toolbox* allows to define fuzzy controllers in a convenient way. Fuzzy control of Mamdani type and Sugeno type are supported. FC1 uses the Mamdani fuzzy model and FC2 the Sugeno model, which provides support for singletons. Also very useful in this toolbox is the included rule base editor, where the rule base of this example is defined.

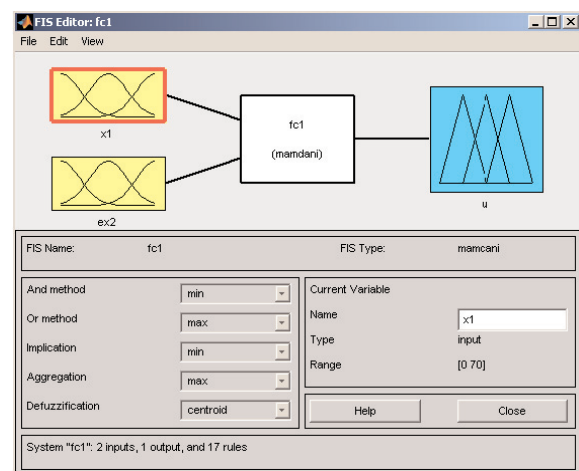


Figure 3: GUI for defining the fuzzy control (FC1).

The controller itself is defined in comfortable graphical user interface (Figure 3). For a better overview the fuzzy controller is put into a submodel with sampling block (Figure 4).

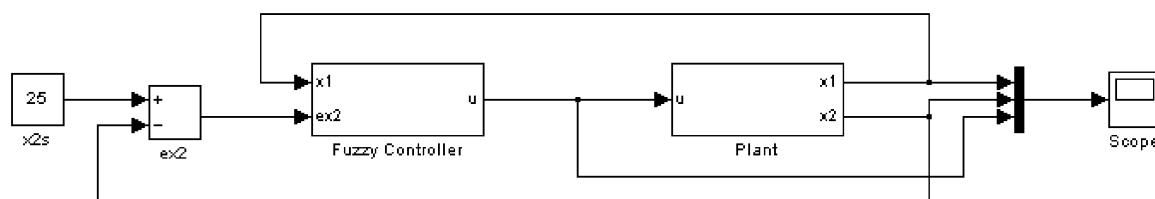


Figure 1: Modular model of the two tank system with fuzzy control.

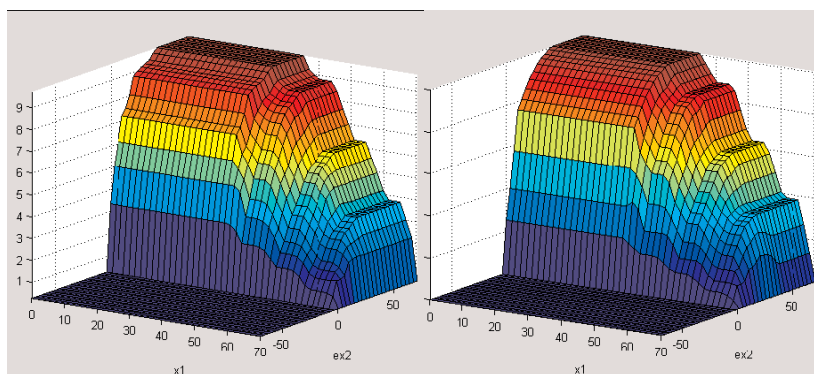


Figure 5: Control surface of FC1 (left) and FC2 (right).

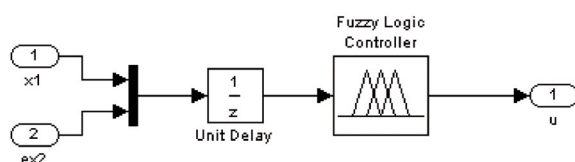


Figure 4: Submodel Fuzzy Controller with discretisation and fuzzy logic module from Fuzzy Control Toolbox.

### A - Task: Computation of Controller Surfaces.

The Fuzzy Control Toolbox generates directly data for the surfaces, with a discrete ramp signal on both inputs. For FC1 and FC2 resp., simply different control types (Mamdani or Sugeno) are chosen in the GUI. The surfaces are plotted by standard MATLAB plot features (Figure 5). Small differences only can be seen for high level of  $x_1$ . The calculation times for these surfaces on a Pentium 4 2.4 GHz machine are  $ta_{FC1} = 0.235s$  and  $ta_{FC2} = 0.078s$ ; the ratio is  $ta_{FC1} / ta_{FC2} = 3$ .

### B - Task: Simulation of the System.

Simulation was performed in the Simulink environment menu-driven. For a simulation horizon of 1000 s the computation times are  $tb_{FC1} = 0.469s$ ,  $tb_{FC2} = 0.219s$ ,

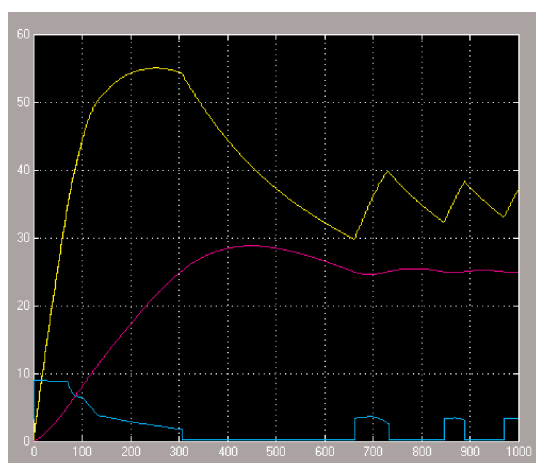


Figure 6: States and control for Mamdani control (FC1).

and ratio  $tb_{FC1} / tb_{FC2} = 2.14$ . Simulation results (Figure 5 and Figure 6) again show differences only for high level of  $x_1$ .

### C - Task: Weighted fuzzy control.

Weighting factors in the rules are a standard feature in the rule editor. The rule base editor allows to specify the weight for each rule in the GUI. The calculation time for the FC3 surface is  $tc_{FC3} = 0.079s$ .

**Résumé:** In this MATLAB/Simulink (Rel. 2006a) solution, the Fuzzy Control Toolbox was used, so that modelling of different fuzzy controls was a standard task. Interestingly, singletons seem to be implemented different to standard membership functions, so that computation times are significantly faster. A specialty in this solution is the discrete model used for the plant: instead of ODEs, difference equations (with stepsize equal to control cycle time) have been used - equivalent to Euler integration of the ODEs with unit stepsize. The results do not differ from results with ODE solvers of higher order and smaller or controlled stepsize.

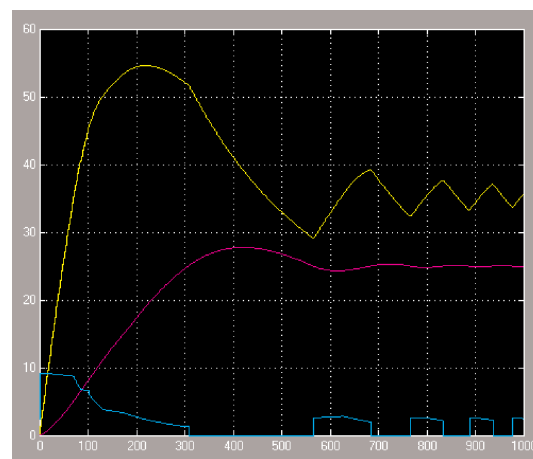


Figure 7: States and control for Sugeno control (FC2).

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