OPTIMIZATION OF FUZZY REGULATOR PARAMETERS BY GENETIC ALGORITHM

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Abstract

Many papers deals with the usage of fuzzy rules to implement PID type control.

Fuzzy models, especially the Takagi-Sugeno-type, have received significant attention from various fields of interest. It is very often very difficult to determine all the parameters of the Takagi-Sugeno-type controller.

In this paper we present optimization of Takagi-Sugeno-type fuzzy regulator parameters by genetic algorithm. Implementation of universal fuzzy P/PS/PD function block implemented to the PLC Simatic S7 300/400 is introduced.

Mamdani model is used as the comparative model. Parameters of Takagi-Sugeno-type fuzzy regulator are determined by genetic algorithm optimization from comparative regulation surface.

1 Introduction

The aim of this work is optimization of Takagi Sugeno-type (TS-type) fuzzy regulator parameters by genetic algorithm. Implementation of universal fuzzy P/PS/PD function block implemented to the PLC Simatic S7 300/400 is introduced.

Mamdani model is used as comparative model. Parameters of TS-type fuzzy regulator are determined by genetic algorithm optimization from comparative regulation surface.

Many papers deal optimization of TS-type fuzzy regulator parameters. [1, 2, 3]

The goal of this work is to design own universal fuzzy control function block for PLC Simatic S7 300/400 with optimized parameters.

Chapter 2 introduces basic knowledge of genetic algorithm.Chapter 3 contains a description of the implemented fuzzy P/PS/PD function block.Optimization and results are given in chapter 4.

2 Genetic algorithm

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems. The genetic algorithm is based on natural selection, the process that drives biological evolution.

The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population is going toward an optimal solution. The genetic algorithm can be applied to solve a variety of optimization problems that are not well suited for standard optimization algorithms.

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population: selection, crossover and mutation.

Selection rules select the individuals, called parents that contribute to the population at the next generation.

Crossover rules combine two parents to form children for the next generation.

Mutation rules apply random changes to individual parents to form children.

The genetic algorithm can be described in the form (1).

$$GA = (p, I, P, f, s, c, m, T) \quad (1)$$

Where

$p^0 = (a_1^0, \ldots, a_r^0)$	initial population of chromosomes,
I	coding of chromosomes,
$P \in N$	size of population,
$L \in N$	length of the chromosome,
$f: I \to R$	the fitness function,
$s: I^P \to I$	selection of chromosome pairs of parents,
$c: I^2 \to I^2$	operation of chromosome crossover,
$m: I \to I$	operation of chromosome mutation,
$T: I^P \to \{0,1\}$	the stop criteria of the genetic algorithm.

3 Fuzzy P/PS/PD regulator

Function block for Siemens Simatic S7 300/400 has been implemented.

Fuzzy controller can be except fuzzy P also fuzzy PS or fuzzy PD according to a logical value of function block input *Sel_PS_PD* (*Sel_PS_PD* in log. 0: PS regulator, *Sel_PS_PD* in log. 1: PD regulator).

For regulation error e the first difference of regulation error Δe and for and manipulated value u (in the case of fuzzy PS regulator the first difference of manipulated value Δu) are implemented weighting factors (K_P, K_S, K_D, K_U). When selecting the type of fuzzy PD regulator the error e is multiplied by K_P factor and the first difference of the error Δe by K_D factor. On the other hand when selecting a fuzzy PS regulator the error e is multiplied by K_S factor and the first difference of the error Δe by K_P factor.

Structure (2) is generally applied for fuzzy PD regulator and structure (3) is generally applied for fuzzy PS regulator.

$$IF(eisA)and(\Delta eisB)THEN(uisC) \quad (2)$$
$$IF(eisA)and(\Delta eisB)THEN(\Delta uisC) \quad (3)$$

Manipulated value calculation for the fuzzy PD regulator is in (4) and for the fuzzy PS regulator in (5).

$$K_u \cdot u(k) = K_P \cdot e(k) + K_D \cdot \Delta e(k) \quad (4)$$
$$K_u \cdot \Delta u(k) = K_P \cdot \Delta e(k) + K_S \cdot e(k) \quad (5)$$

The range of control error e and the first difference of the error Δe is divided up to seven fuzzy sets (NB - Negative Big, NM - Negative Medium, NS - Negative Small, AZ - Approximately Zero, PS - Positive Small, PM - Positive Medium, PB - Positive Big).

Takagi-Sugeno method was used for inferring the manipulated values (6).

$$IF(eisA)and(\Delta eisB)THEN\mathrm{u} = \mathrm{f}(e, \Delta e) \quad (6)$$

The final output is determined as a weighted mean value over all rules according to (7).

$$u = \frac{\sum_{i=1}^{r} \alpha_i \cdot w_i \cdot (u_i + a_i \cdot e + b_i \cdot \Delta e)}{\sum_{i=1}^{r} \alpha_i \cdot w_i} \tag{7}$$

Where

$u_i,\ a_i,\ b_i$ parameters of Takagi Sugeno model,

α_i it is given as a minimum value of membership of members of the antecedent (corresponding to the logical AND in the antecedent),

w_i weighing factor of the rule,

u calculated manipulated variable.

Fuzzy regulator contains an initialization procedure that will get the coordinates of fuzzy sets e, Δe and parameters of Takagi Sugeno model from input structures into static structures of the fuzzy controller.

Initialization procedure also checks the coordinates of fuzzy sets so that any bad assignment of fuzzy sets and no fatal impact to the regulation function should be applied. If errors are detected in the coordinates of fuzzy sets during initialization procedure, the control is stopped and indication of wrong is appeared in function block output.

The block scheme of implemented function block is on Fig. 1.

The interface of the implemented function block is shown on Fig. 2.

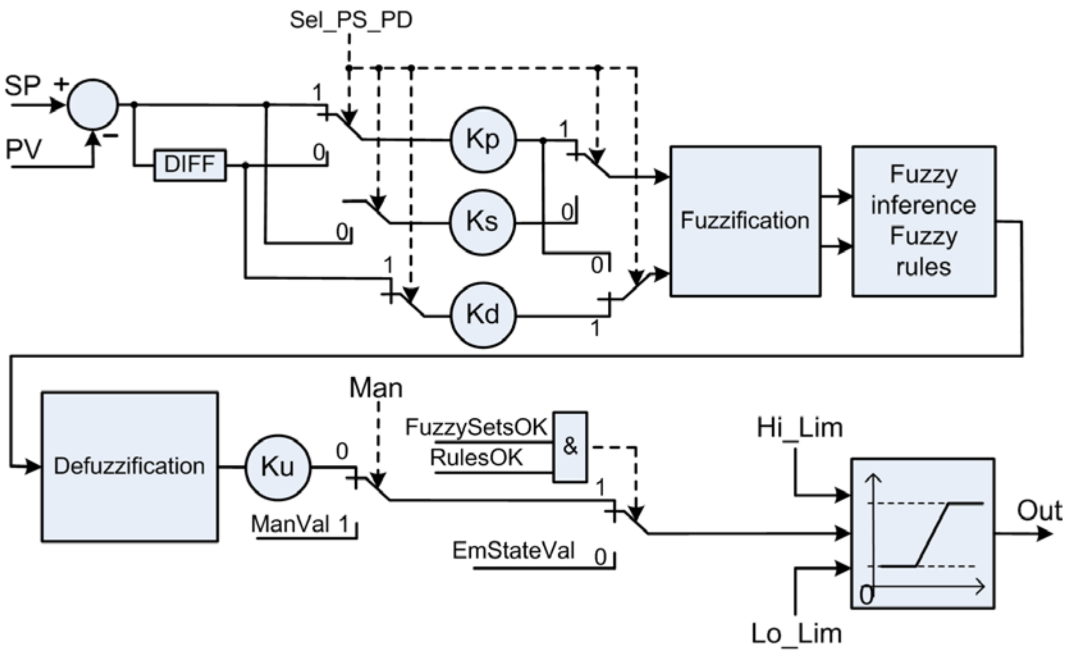

Fig. 1. The block scheme of fuzzy PS/PD regulator.

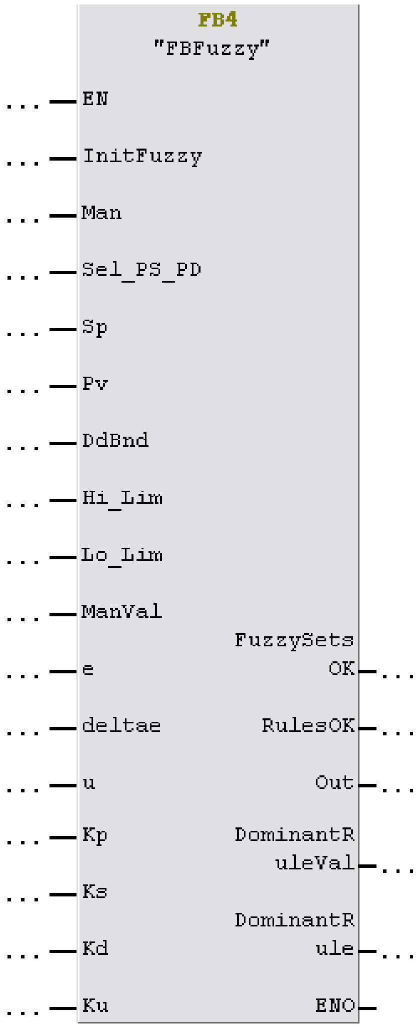

Fig. 2. Implemented fuzzy P/PS/PD regulator.

4 Optimization of parameters by genetic algorithm

With comparison to Mamdani model, TS fuzzy model brings one significant advantage but also one significant disadvantage. Final implementation of Takagi Sugeno type fuzzy model to some control system is often much more convenient.

Deffuzification method for TS-type fuzzy model needs less computing time than Mamdani CG defuzzification method. But on the other hand it is very difficult and even impossible to set all parameters of Takagi Sugeno model correctly without some automatic algorithm. Therefore, many optimization methods are used to solve this problem.

Optimization by genetic algorithm is used in this approach. Mamdani model is used for comparative purposes.

Genetic algorithm Toolbox in Matlab is used.

We have used "ga" function from Matlab:

[X, FVAL, EXITFLAG, OUTPUT] = GA (FITNESSFCN, NVARS, A, b, Aeq, beq, lb, ub, NONLCON, options).

The GUI (Fig. 3) is designed to set up and control the optimization procedure (number of populations, number of chromosomes in population, parameters limits, start optimization etc.).

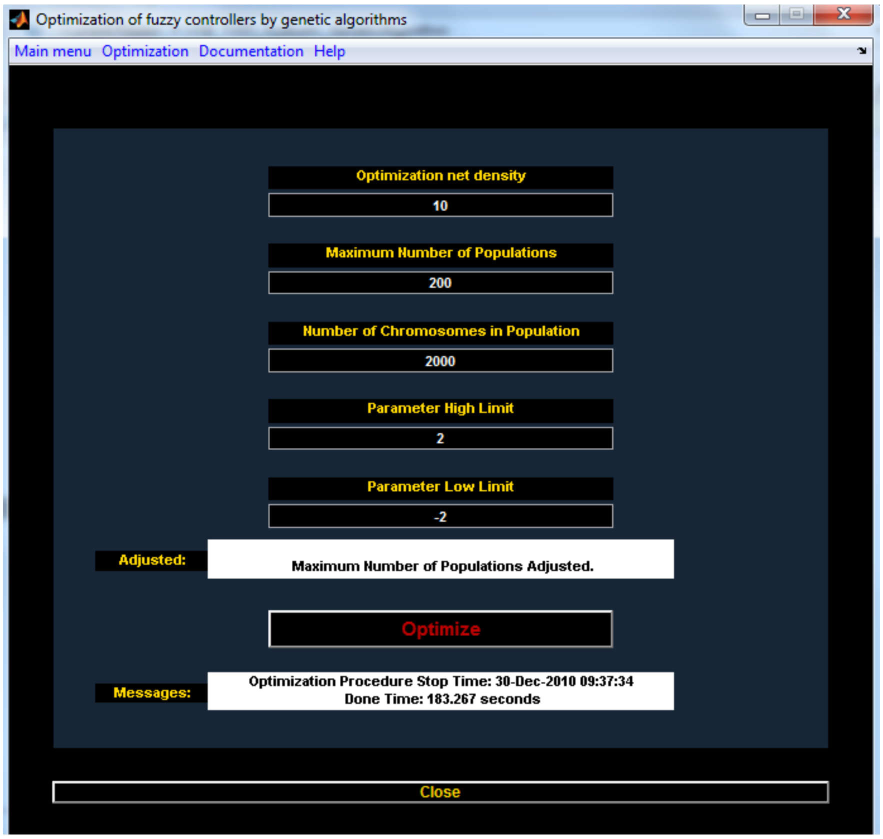

Fig. 3. Matlab GUI for optimization.

The genetic algorithm minimizes the fitness function (8).

$$y_{val} = \frac{1}{(\sum_{i=1}^{r} abs(y_i - y_{GA,i})) + 1} \tag{8}$$

Where

y_{val} output value from fitness function,

y_i value of i-th part of comparative regulation curve or surface (from Mamdani model),

$y_{GA,i}$ value of i-th part of regulation curve or surface determined by genetic algorithm (TS model).

Fitness function (8) minimizes the sum of the differences across all TS fuzzy model parameters in function values between comparative Mamdani model and the TS model.

4.1 P fuzzy type regulator optimization

Comparative regulation curve of Mamdani fuzzy model (Fig. 4) is determined for fuzzy P regulator optimization.

Fig. 5 contains optimized regulation curve of TS fuzzy model. Fuzzy model with three fuzzy sets were used.

Optimized parameters of fuzzy P regulator:

$$u_1 = -0{,}142 \cdot e - 0{,}5823$$
$$u_2 = -1{,}2794 \cdot e - 0{,}0005$$
$$u_3 = -0{,}4268 \cdot e + 0{,}3765$$

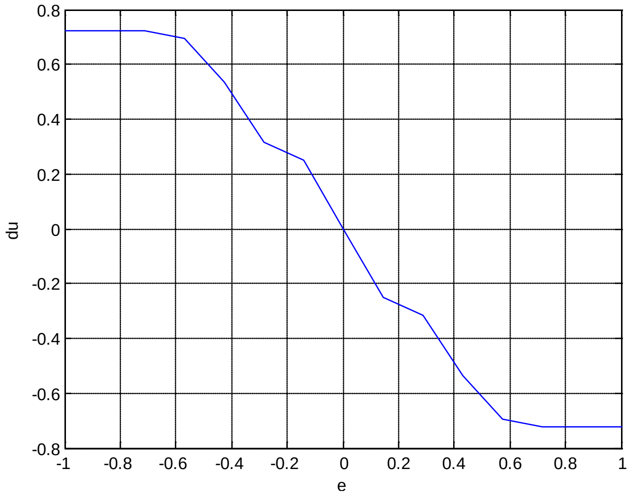

Fig. 4. Comparative regulation curve.

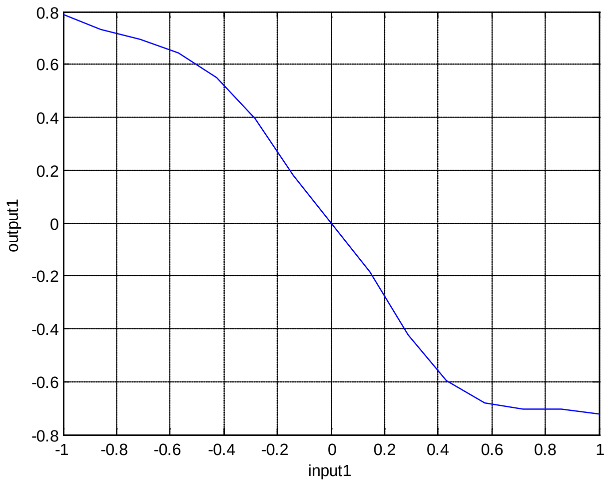

Fig. 5. Optimized regulation curve of TS model.

4.2 PS/PD fuzzy type regulator optimization

Regulation surface of Mamdani fuzzy model (Fig. 6) is determined for TS fuzzy PS/PD regulator.

Fig. 7 shows optimization procedure in progress. Fig. 8 contains finally optimized regulation surface of TS fuzzy model. Fuzzy models with three fuzzy sets are shown.

Optimized parameters of fuzzy PS regulator:

$$du_1 = 0{,}4284 \cdot e + 0{,}4673 \cdot de - 0{,}0914$$

$$du_2 = -0{,}3780 \cdot e + 1{,}1180 \cdot de - 1{,}0197$$

$$du_3 = 0{,}6289 \cdot e + 0{,}5416 \cdot de - 0{,}3034$$

$$du_4 = 0{,}1429 \cdot e - 0{,}2764 \cdot de - 0{,}9857$$

$$du_5 = 0{,}5452 \cdot e + 0{,}5673 \cdot de + 0{,}0001$$

$$du_6 = 0{,}9321 \cdot e + 0{,}3144 \cdot de + 0{,}4729$$

$$du_7 = 0{,}3666 \cdot e + 0{,}4225 \cdot de + 0{,}1675$$

$$du_8 = -0{,}0577 \cdot e + 1{,}0996 \cdot de + 0{,}1675$$

$$du_9 = 0{,}4808 \cdot e + 0{,}7011 \cdot de - 0{,}1321$$

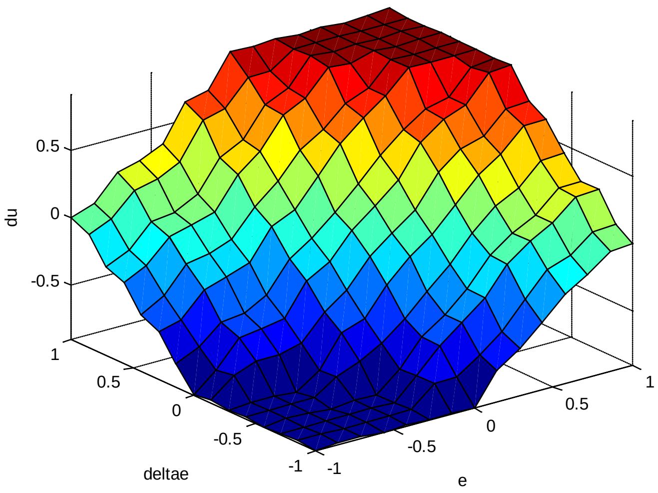

Fig. 6. Comparative regulation surface.

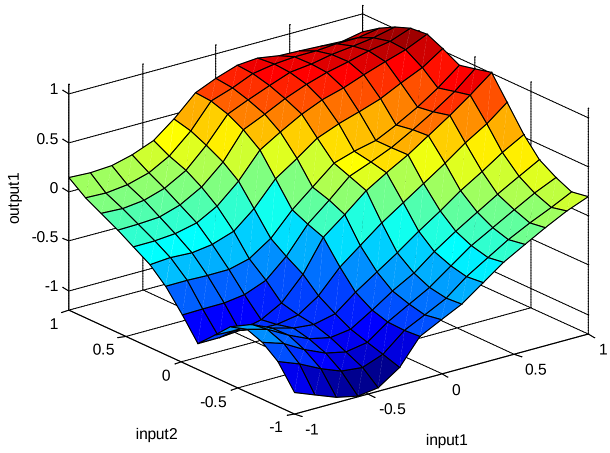

Fig. 7. Optimization of TS model in progress.

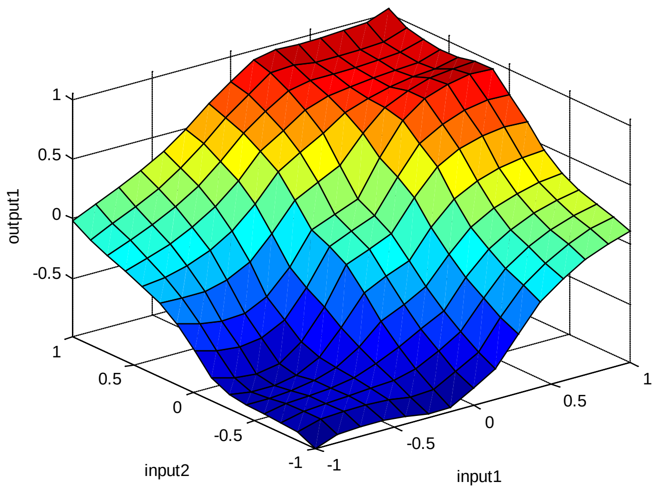

Fig. 7. Finally optimized regulation surface of TS model.

5 Conclusion and future work

The aim of this work is optimization of Takagi-Sugeno-type fuzzy regulator parameters by genetic algorithm. Implementation of universal fuzzy P/PS/PD function block implemented to the PLC Simatic S7 300/400 is introduced.

Mamdani model is used as comparative model. Parameters of Takagi-Sugeno-type fuzzy regulator are determined by genetic algorithm optimization from comparative regulation curve or surface.

The goal of this work is also design own universal fuzzy control function block for PLC Simatic S7 300/400with optimized parameters.

Future work will cover online optimization of TS model according regulated system parameters.

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