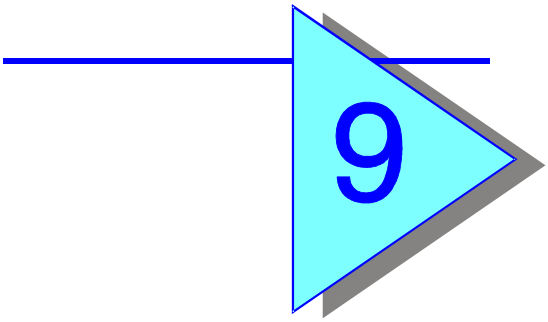
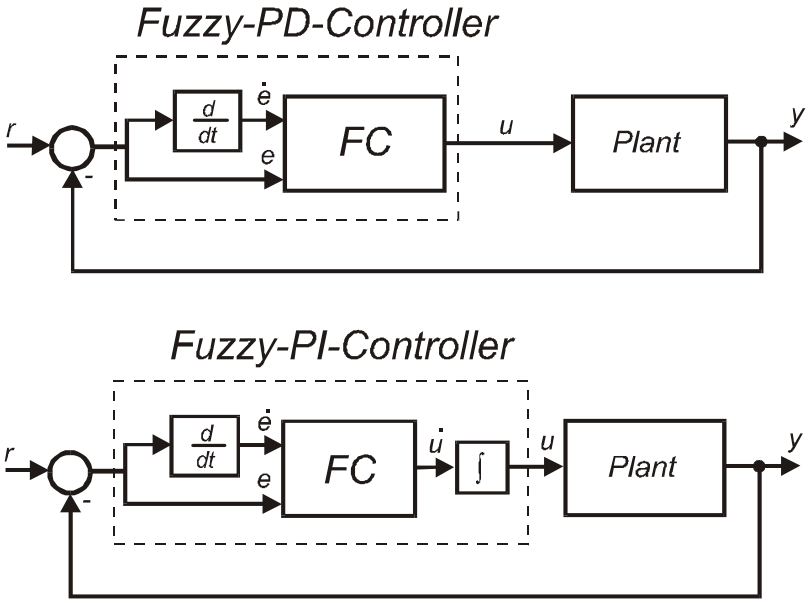


Design of simple Fuzzy-PID-controllers with FuzzyPID

Overview	**2**
Main window structure	**3**
Control loop	**5**
Simulation	**8**
Options	**11**
Sample files	**12**

Overview

The FuuzyPID program allows an interactive design of a Fuzzy-PI- resp. Fuzzy-PD-controller for a standard control loop with a linear plant. The closed-loop system can be simulated representing all time responses graphically. FuzzyPID is especially recommended for first experiments in the field of Fuzzy Control as well as for demonstration and training purposes. More complex control loops should be designed with BORIS.



Simple control loop with Fuzzy-PD-controller (top) resp. Fuzzy-PI-controller (bottom)

User interface and concept of FuzzyPID are similar to those of the fuzzy shell FLOP described in chapter 7. The following restrictions are to be noticed:

- The linguistic variables have the following identifier:
  - *e* for the error variable *e*,
  - *de/dt* for the change $\dot{e}$ of the error variable,
  - *u* for the manipulated variable (control loutput) *u* (Fuzzy-PD-controller),
  - *du/dt* for the change $\dot{u}$ of the manipulated variable (Fuzzy-PI-controller).

These identifiers are fixed by the program and thus cannot be changed. Also linguistic variables cannot be deleted.

- The number of linguistic terms per linguistic variable is set to five and cannot be changed. The terms have the following names for all variables:

  Negative_Big (Abbreviation --),
  Negative_Small (Abbreviation -),
  Zero (Abbreviation 0),
  Positive_Small (Abbreviation +),
  Positive_Big (Abbreviation ++).

- The controller and therefore the rule base must have two inputs - the variables e and $\dot{e}$. Thus if you like to design a Fuzzy-P-controller you have to select the Fuzzy-PD-Controller first and afterwards you have to fill the rule base in such a way that the generated control output is independent of $\dot{e}$. This can be done be specifying identical conclusion terms in all cells of each row of the rule base.
- All rules are weighted by the value 1. Negated premises are not allowed.

Because the general operations like the definition of fuzzy sets and rule base are similar to those described in chapter 7 this chapter only deals with operations that are specific for the work with FuzzyPID.

Main window structure

FuzzyPID contains all relevant information within its main window:

- The structure of the corresponding closed-loop system
- The membership functions for the inputs and outputs of the controller
- The current rule base

- The simulation results

The screenshot below shows the main window of FuzzyPID directly after starting the program. You can recognize that the rule base is still empty and all membership functions are identical. The main menu of the program contains the following submenus which will be discussed in the next chapters:

- FILE

  Allows the in- and output of system data to/from a file with FUZ extension. These files include all membership functions (fuzzy sets) as well as the rule base and are compatible to the fuzzy shell FLOP. Thus fuzzy controllers designed with FuzzyPID can be analyzed with FLOP and vice versa. The items of this submenu are similar to those of the fuzzy shell FLOP.

- CLOSED LOOP

  Includes all menu items for the selection of plant, controller type, reference variable and simulation parameters.

- VARIABLES

  Allows the modification of linguistic variables and their linguistic terms.

- RULEBASE

  Allows the modification of the rule base.

- SIMULATION

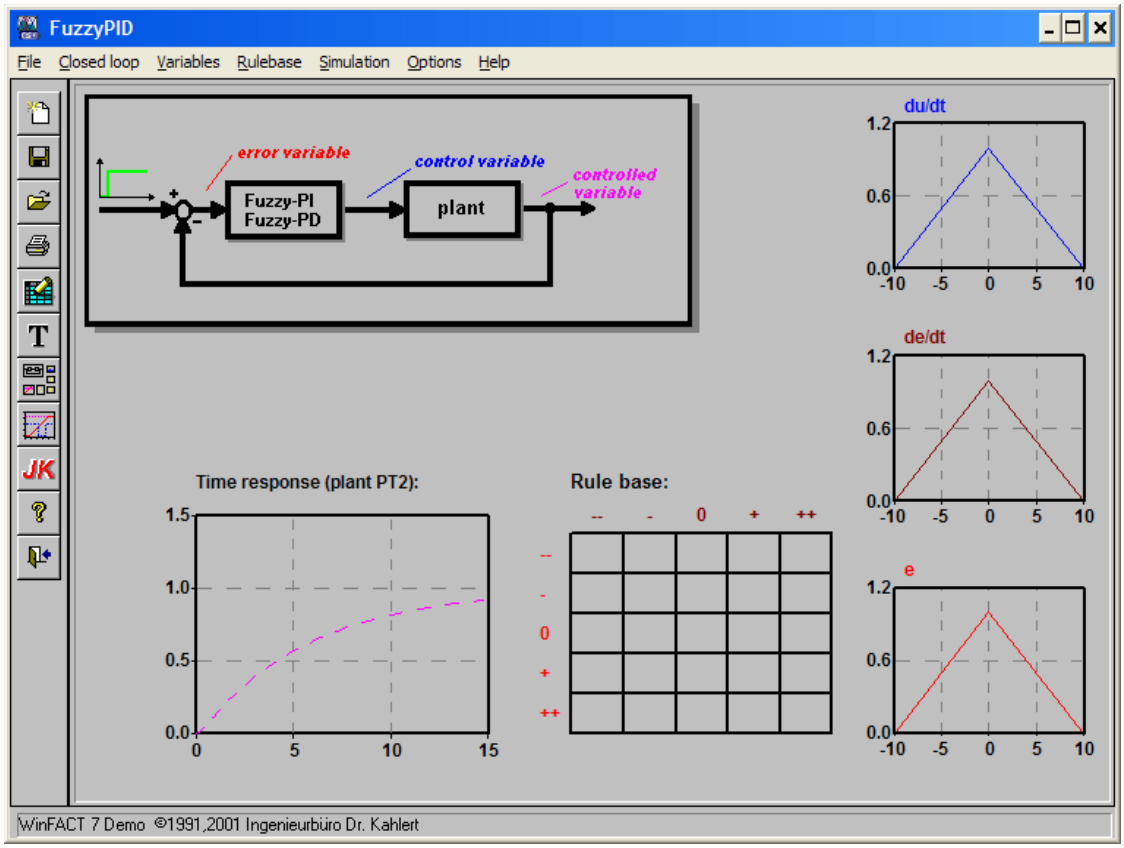
  Starts a simulation run. This menu item is only enabled after a rule base has been specified resp. loaded from file.

- OPTIONS

  Contains some program options like the selection of inference mechanism, defuzzification method and those time responses which are displayed during a simulation.

- HELP

  Calls the online help or shows an *About...* dialog box.



Main window of FuzzyPID after starting the program

Control loop

The closed-loop system FuzzyPID deals with has a simple structure with a feedback of the controlled variable (plant output). For first experiments in the field of fuzzy control the plant can be selected out of five pre-defined plant types via the CLOSED LOOP | PLANT menu option:

- PT_2-plant (non-oscillating)

  This plant type has a gain of 1 and two real eigenvalues. The corresponding time constants are $T_1 \approx 0.2$ s and $T_2 \approx 5$ s. Thus the corresponding transfer function has the form

$$G(s) = \frac{1}{s^2 + 6s + 1}.$$

- PT_2-plant (oscillating)

  This plant type has two conjugate complex eigenvalues and is therefore able to oscillate. The damping is $\zeta = 0.25$, the eigenfrequency $\omega_n = 1$. Thus the corresponding transfer function has the form

$$G(s) = \frac{1}{s^2 + 0.5s + 1}.$$

- PT_1-I-plant

  This plant type is a serial connection of a PT_1-plant with a time constant of $T = 10$ s and an integrator. The corresponding transfer function is

$$G(s) = \frac{0.2}{s(1 + 10s)}.$$

- PT_1-T_t-plant

  PT_1-element with dead time. The PT_1-element has a time constant of $T = 5$s. The dead time has a value of $T_t = 3$s. Thus the corresponding transfer function has the form

$$G(s) = \frac{1}{1 + 5s} e^{-3s}.$$

- PT_2- plant (time-variant)

  This plant type has the same structure as the oscillating PT_2-plant but is characterized by a time-variant gain:

$$G(s) = \frac{K(t)}{s^2 + 0.5s + 1}.$$

  For $0 \le t \le 5$ the gain raises linear from 1 to 2, for $5 \le t \le 10$ it falls down again to 1:

$$K(t) = \begin{cases} 1 + t/5 \quad for \quad 0 \le t \le 5 \\ 2 - (t-5)/5 \; for \quad 5 < t \le 10 \\ 1 \quad for \quad t > 10 \end{cases}$$

For all of these plant types a modification of plant parameters is not possible.

The last three options within the CLOSED LOOP | PLANT submenu allow the specification of any other linear plant in form of a transfer function. This can be specified via keyboard or loaded from a UFK-file as well as saved to a UFK-file again.

As controller types Fuzzy-PI- and Fuzzy-PD-controller are selectable. Input variables of the controller are in both cases the error variable e and its change $\dot{e}$, output variable is the change $\dot{u}$ of the manipulated variable (Fuzzy-PI-controller) resp. the manipulated variable u itself (Fuzzy-PD-controller). The controller type can be selected via the CLOSED LOOP | CONTROLLER TYPE PI resp. CLOSED LOOP | CONTROLLER TYPE PD menu option.

The menu item CLOSED LOOP | SIMULATIONS PARAMETERS... or the <Ctrl><P> shortcut leads to the simulation parameters dialog. This dialog allows

- the specification of the simulation time,
- the selection of the number of simulation steps,
- the modification of the simulation speed.

It may be recommended to decrease the simulation speed e. g. if the simulation shall be analyzed exactly on a very fast PC.

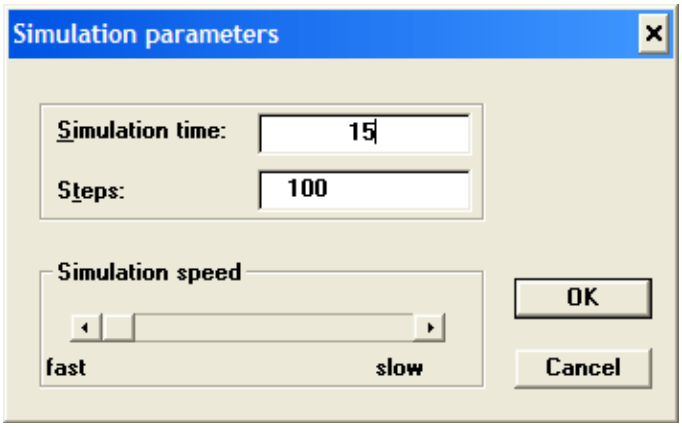
The reference variable $r(t)$ for the control loop can be selected among three different test signals:

- a step-sized signal of amplitude 1,
- a ramp-sized signal with the gradient

  $$\frac{\Delta r}{\Delta t} = \frac{2}{T_{\mathrm{End}}}$$

  and a maximum amplitude of 1 in which T_{End} denotes the simulation time,
- a double-pulse given by

$$r(t) = \begin{cases} 1 & for \quad 0 < t \le T_{End}/3 \\ -1 & for \quad T_{End}/3 < t \le 2T_{End}/3 \\ 0 & for \quad t > 2T_{End}/3 \end{cases}.$$



Dialog for simulation parameters

Simulation

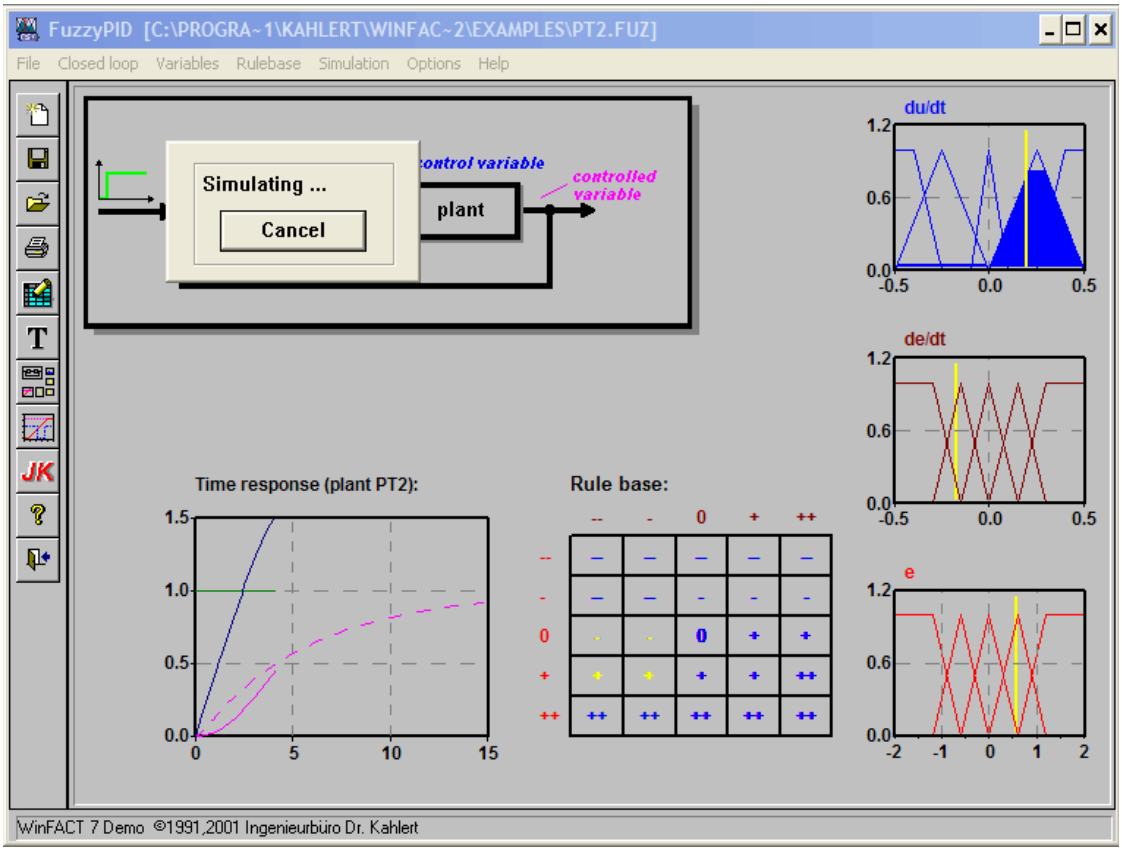
After membership functions and rule base have been defined resp. loaded from file the simulation can be started. For this two different modes can be selected which differ especially in the representation of the simulation results.

The SIMULATION | DISPLAY ALL menu option resp. the <Ctrl><S> shortcut start a simulation run where all relevant data are represented directly within the main window of the program:

- Within the diagrams containing the membership functions of the in- and output variables of the controller at the right window margin the current values of the variables are represented as vertical yellow lines. The top diagram containing the manipulated variable resp. its change (depending on the selected controller type) furthermore displays the active output fuzzy sets and their match of degree (blue hatched).

- Within the rule base those rules that are active are drawn in yellow.
- The diagram in the lower left area of the window shows the time response of all variables which were activated via the *Options* dialog before. These are:
  - The time response of the separated plant (i. e. without controller and feedback, dashed violet curve)
  - The reference variable $r(t)$ of the closed-loop system (solid green curve)
  - The controlled variable, i. e. the output variable $y(t)$ of the closed-loop system (solid violet curve)
  - The error variable $e(t)$ (solid lightred curve)
  - The change $\dot{e}(t)$ of the error variable (solid red curve)
  - The manipulated variable $u(t)$ (solid darkblue curve)
  - The change $\dot{u}(t)$ of the manipulated variable (solid lightblue curve, only if a Fuzzy-PI-controller is used)

The simulation can be terminated via the *Cancel* button at any time.



Main program window during simulation

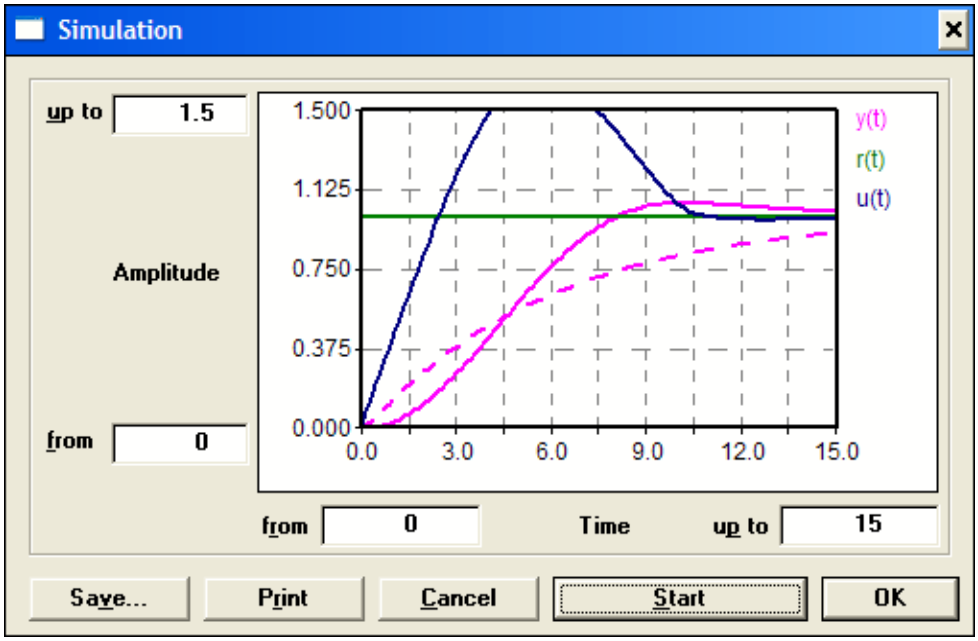
If only the time responses of the closed-loop system are of interest it might be better to choose the SIMULATION | TIME RESPONSE menu option resp. the <Ctrl><V> shortcut. The dialog window shown by the screenshot below appears which displays all time responses in a much better way than the simulation mode discussed before, especially because it allows modification of the axes scaling[1]. When this dialog appears it already contains the response of the seperated plant. The calculation of the other variables is started via the *Start* button. Because the time-intensive display of the membership functions as it appears in the earlier simulation mode is not necessary here this simulation executes much faster.

Beacuse the change $\dot{e}$ of the error variable can take very large values during the simulation in the case of a step-sized reference function, this variable is automatically limited to the specified range of the corresponding linguistic variable.

At the upper margin the simulation dialog contains some more options:

[1] Please note that a new scaling of the time axis only modifies the displayed area but not the simulation time itself!

- The *Print* button allows to print the results on the standard printer
- The *Save*... button allows to save all simulated responses in SIM-files. After selecting this option a popup menu appears where the variable to be saved can be selected.

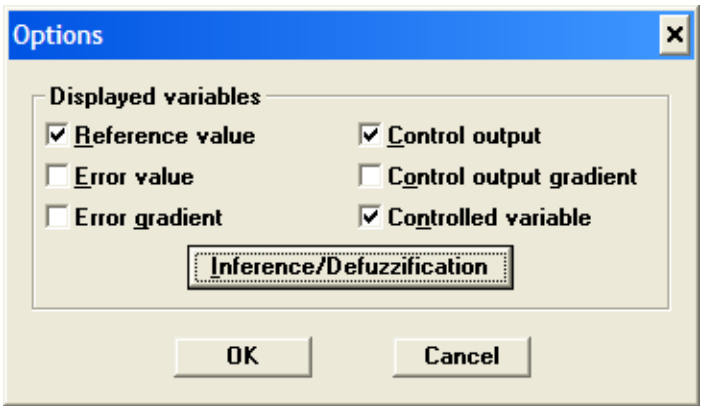


Time response simulation dialog

Options

The OPTIONS menu of the main menu leads to an input dialog where some parameters can be modified:

- The variables to be displayed in the simulation dialog (see above)
- Inference mechanism and defuzzification method
- The fuzzy controller behaviour if no rule is active



Options dialog

Sample files

The Examples-directory of your WinFACT installation contains a sample file for all plant types and a step-sized reference variable. These fuzzy controllers already work in a satisfying way and thus can be used as initial settings for own experiments. The files have the following filenames:

PT2.FUZ	Fuzzy-PI-controller for PT_2-plant (non-oscillating),
PT2S.FUZ	Fuzzy-PI- controller for PT_2-plant (oscillating),
PT1I.FUZ	Fuzzy-PD- controller for PT_1-I-plant,
PT1TT.FUZ	Fuzzy-PI- controller for PT_1-T_t-plant,
PT2ZV.FUZ	Fuzzy-PI- controller for PT_2-plant (time-variant).

The appropriate controller type (PI resp. PD) is automatically set when the corresponding file is opened.

