PIDlab.com

Fractional PID laboratory1.2

User Guide

April 2006

Contents

1 Introduction

Dear PIDlab visitor or user!

In this report, the brief GUI description of the Java applet *Fractional PID laboratory 1.2* is given. On the contrary, here is not place to introduce the process control theory. However, useful links to theoretical papers that can help a lot to understand basic applet ideas are given below.

Firstly, let us explain the word **Fractional** in the applet title. It means that we can use the *Fractional calculus* in both identification and controller design. But even if we want to design the traditional PID controller for a simple model (e.g. first/second order plus dead time) this applet is the right solution. Note, that the *'Fractional PID laboratory'* is the significant improvement of older popular *'PID Controller Designer'* and adopts all its features. In fact the development of *'PID Controller Designer'* was already stopped and the only reason to use it may be an old computer with low performance.

To understand and use all applet features effectively it is supposed that you are familiar with following process control concepts and ideas (some of them are briefly described on PIDlab)

- *Frequency response of the process*
- *Nyquist plot*
- *Gain and phase margins*
- *Sensitivity and complementary sensitivity function*
- *M-circles*
- *2DOF ISA form of PID controller*
- *standard control loop and its signal notation*

If you want to use the applet just for designing the PID controller for known process model given by transfer function, you should read the following papers

- *Basic paper about robustness regions in 'PID Controller Designer'*
- *General shaping of sensitivity functions*

If you want to design controller from experimental data it is highly recommended to read besides above mentioned papers a few theoretical papers about following topics

- *computing value sets from moments of the impulse response*
- *computing value sets from one sample of the frequency response*
- *combining above mentioned characteristic numbers*

If you want to design the fractional-order PID controller you can find useful comparison of PID and $PI^{\alpha}D^{\beta}$ in following papers

- *Fractional PID controller design on Internet: www.PIDlab.com*
- *Fractional-order PID controller outperforms the classical one*

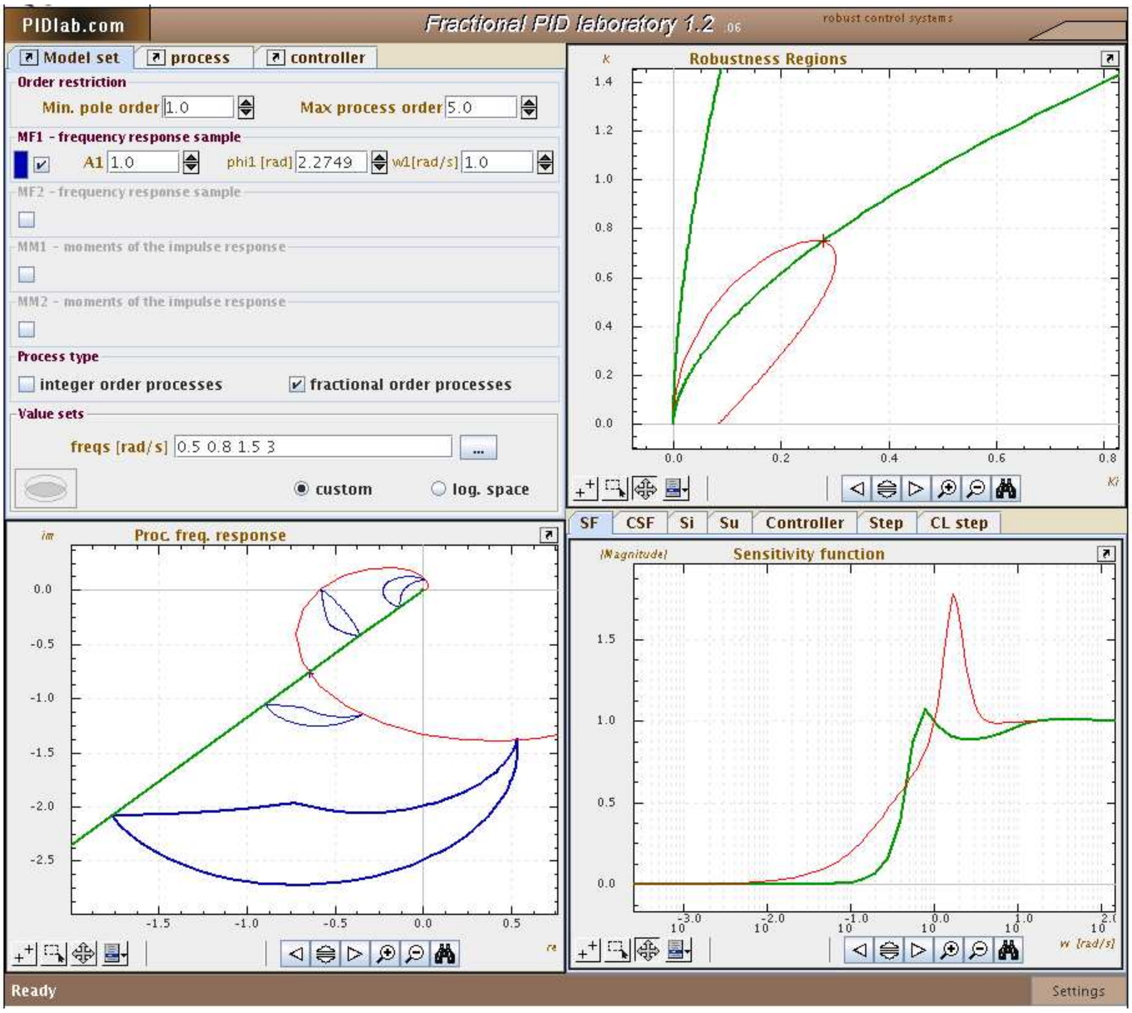


Figure 3.1: Overall view of the *Fractional PID laboratory*.

2 SW and HW requirements

- *operating system*: Windows 98/2000/NT/ME/XP, Linux, Solaris or other Java platform
- *Java Virtual Machine version*: JRE 5.0 or higher
- *HW for comfort use*: CPU speed at least 1GHz, memory at least 256MB, screen resolution 1024x768 or more

3 Applet user description

The brief description of the applet is given in this section. Note, that many GUI elements (buttons, text fields, checkboxes) are not visible or not enabled if they have no sense in the current context.

3.1 Basic graphical elements

The following graphical elements are the basic stones of the applet and it is necessary to be familiar with them.

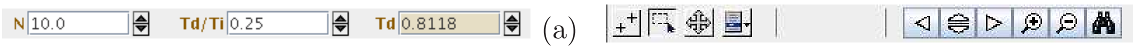


Figure 3.2: a) number input field, b) axes panel buttons

3.1.1 Number input field

The most of number values can be changed in number input fields (Fig. 3.2 a) that are complemented by arrows for increasing/decreasing the field value. The change step is different for each parameter. Moveover, the step can be linear or logarithmic. The value can be changed also by mouse wheel, if the mouse cursor is over the input filed. If the new value is set by hand from keyboard it should always be confirmed by `Enter`.

3.1.2 Graph panel

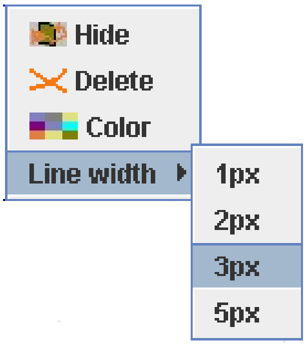
The applet contains a lot of graphs that can be handled by buttons situated below each graph (Fig. 3.2 b). The buttons have in left-right direction the following functionality

- *View switch lines/points* – If active, the computed points are drawn as crosses, otherwise they are connected by linear line segments.
- *Mouse zoom* – If active, one can set the rectangle area to zoom by mouse dragging while the other activities are disabled. The zoom UNDO can be done by right mouse button click, the double click performs autoscale function. Even if the button is not active one can zoom very effectively by mouse wheel. If one wants just one axis to be scaled, mouse dragging or mouse wheel in the axis labels area should be used.
- *Axes shifting* – If active, the axes can be shifted by mouse dragging in the free area of the graph panel. The same can be done with cursor keys.
- *Axes settings* – The button activates the axes settings dialog (Fig. 3.3b). We can change axes ranges, font size and also lock any axis. If the axis is locked, the labels area background is red colored and there is further no way to change range of this axis until it is unlocked. Axes lock status can be switched very easily by mouse click in the axes labels area.
- *Buttons for axes shifting, zoom in and zoom out* – they has a clear intuitive functionality
- *Autoscale button* – Automatically sets the axes ranges in according to the set of currently viewed graphical objects.

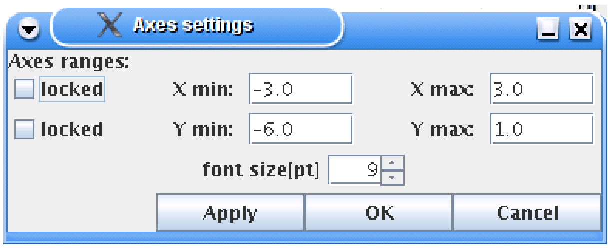
In the upper right corner, there is an *undock* button that moves the graph panel to the separated window. Then the window can be for example enlarged to the full screen. When the window is closed, the graph is docked back to the applet to its original place.

In the graph panel, the mouse cursor changes its appearance in according to the actual mode:

- *standard* – if the mouse zooming mode is chosen
- *cross* – if the mouse zooming mode is not active
- *hand* – if the cursor is over the object which can be shaped or moved by mouse dragging
- *cross with arrows* – if the object is currently being moved or shaped by mouse dragging



(a)



(b)

Figure 3.3: a) context pop-up menu, b) axes settings panel

Moreover, the context tooltip appears if the cursor is over the object which can be shaped or moved by mouse dragging.

Additional useful information is showing in the upper part of the graph panel if one drags the mouse over some object. For example if the mouse is dragged over the frequency response the phase, amplitude and frequency of the selected point is shown there.

3.1.3 Context pop-up menu of graphical objects

Using a right mouse button click, the context pop-up menu of the graphical object (line, cross, circle) can be activated. The menu contains following default items (Fig. 3.3a):

- *Hide* – hides the graphical object
- *Delete* – deletes the graphical object
- *Color* – opens the color chooser dialog
- *Line width* – sets new line width for the graphical object (the lines corresponding to selected process and design specification have fixed width 2px)

Some graphical object have several of these items disabled. Sometimes, the change of graphical object settings can affect also related objects. For example, if the color of the sensitivity function is changed also all characteristics related to the process adopt the new color. The context menus of some graphical objects are extended by other useful items.

3.2 Applet layout

The applet area is divided into four panels (Fig. 3.1):

1. **Tabs panel (TP)** – upper left panel
2. **Frequency responses panel (FRP)** – lower left panel
3. **Robustness regions panel (RRP)** – upper right panel
4. **Closed loop performance panel (CLP)** – lower right panel

3.3 Tabs panel

One of three tabs can be selected

1. *Model set* – model set definition (if experimental data are available)

2. *Process* – table of processes and custom transfer function definition
3. *Controller* – design specifications definition, controller parameters and Nyquist plot shaping

If the experimental data from the process (moments of the impulse response, sample of frequency response) are available we should start with *Model set tab* and then move to the *Controller tab*. In this case the *Process tab* is used just to check the list of processes chosen from model sets for robust controller design. In such a way the controller is designed in according to the model set approach. On the contrary if one wants to use user-defined process models in the form of linear transfer function then the *Model set* tab should be skipped and the *Process tab* is the starting point.

3.3.1 *Model set*

We can use this tab only if experimental data (frequency response samples, moments of the impulse response) are available. Here we can define (from top to the bottom):

- *Min. pole order* – minimum pole order m of the *a priori* admissible transfer function. If we consider only IO processes then $m = 1$.
- *Max. process order* – maximal total order n of the process transfer function.
- *MF1* a *MF2* – if the checkbox is selected the user can define one sample of the frequency response (amplitude, phase, frequency).
- *MM1* a *MM2* – if the checkbox is selected the user can define two moment model sets in the form K, μ, σ^2.
- *integer order processes, fractional order processes* – these checkboxes activate IO or FO class of processes.
- *frequencies* – list of frequencies for which the value sets of active model sets will be computed and drawn.
- *custom / log. space* – if *custom* is selected the input field *frequencies* is interpreted as a list of frequencies. If the choice *log. space* is active the input field accepts only three numbers *min, max, count* that define a logarithmicaly spaced list of frequencies.
- *"intersection button"* – the button in the lower left corner of the *value sets* panel computes intersections of value sets of all active model sets. It should be used if more experimental data are available (at least two model sets). The intersection leads to the reduction of uncertainty in the frequency domain.

3.3.2 *Process*

This tab containes the list of processes that will be further used for robust controller design. Processes can be of two types:

- *Model set processes (MSP)* – they can be chosen from any active model set (for example by mouse click at the value set boundary). If we change some model set parameter, all processes that were in the past derived from this model set will be deleted automatically.
- *Custom processes (CP)* – arbitrary IO transfer function defined by user using a dialog activated by *Add* button.

The table of processes contains five columns with the following meaning:

1. *title* – If the process is selected from the active model set the title `"ExtremeXX"` or `"UtimateXX"` is set automatically, where XX is the number of the process. The title `"CustomTF"` is default for user defined processes. The title can be changed after clicking at the proper field in the process table.
2. *transfer function* – for user defined processes the transfer function change dialog appears after clicking at this field.
3. *MS* – for MSP contains the name of the parent model set (*MF1*, *MF2*, *MM1* or *MM2*)
4. *Col* – color for drawing all process characteristics and also robustness regions belonging to this process. The color chooser dialog can be activated by mouse click.
5. *Act* – checkbox for hiding/showing all process characteristics.

Always one process is selected (highlighted) in the table. All characteristics and robustness regions of the selected process are emphasized by thick line. The selected process can be deleted by `Delete` key. Below the table, there are five buttons with following meaning:

1. *Delete* – deletes currently selected process in the table
2. *Delete All* – deletes all processes in the table
3. *Color* – opens the color chooser dialog
4. *Add TF* – opens the dialog for adding new custom transfer function
5. *Add extremal processes* – adds to the table extremal processes of all active model sets

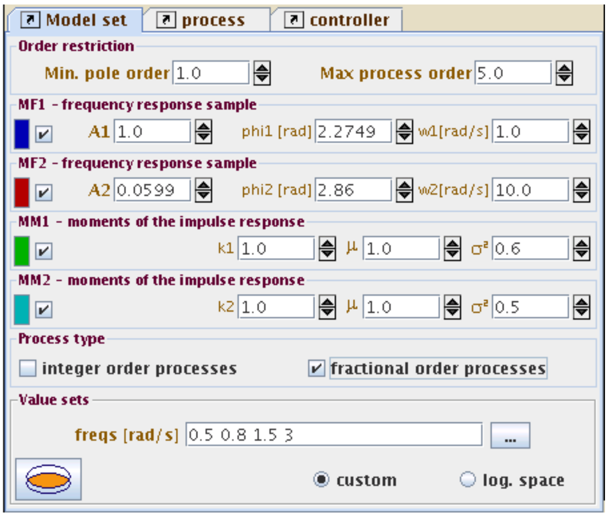
The transfer function dialog (Fig. 3.5 b) enables to define the user transfer function in one of four forms

1. *SOPDT* – second order plus dead time model
2. *num/den* – coefficients of transfer function numerator and denominator in descending power
3. *zero/pole* – zeros and poles of the transfer function
4. *Bode* – time constants of the numerator and denominator

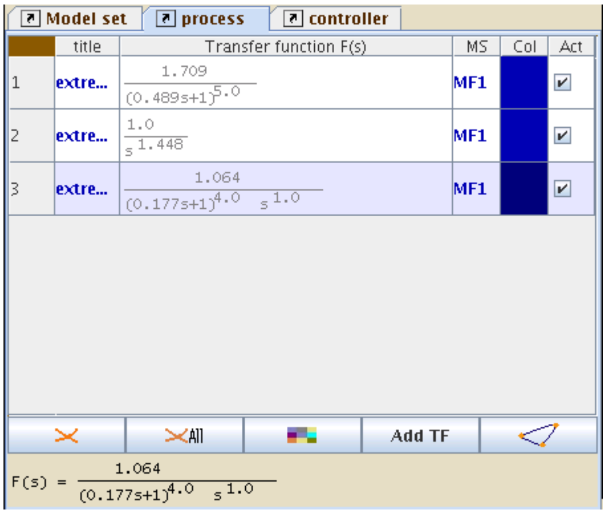
All of these forms can be complemented by gain (G), time delay (D), and astatism (A) of maximum order 2. The current form of the transfer function is always shown in the lowest part of the dialog.

All parameters of the 2DOF $\mathrm{PI}^{\alpha}\mathrm{D}^{\beta}$ controller can be viewed and changed in the upper part of this tab (Fig. 3.6 a). If we enter this tab for the first time only the following fields are visible:

- *PI/PID/FPID selector* – the type of the controller to design
- *N*,T_d/T_i *parameters* – we have to choose *a priori* the derivative filter N and the ratio between derivative and integral time constant $f = T_d/T_i$.
- α,β *parameters* – if the $FPID$ controller is chosen then also the integrator and derivator order can be set.

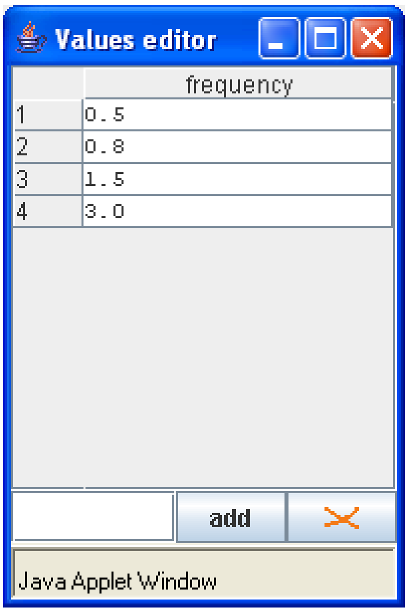


(a)

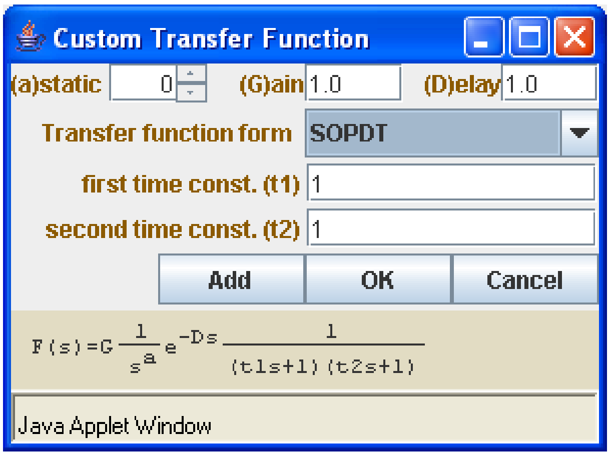


(b)

Figure 3.4: a) *Model set* tab, b) *Process* tab.

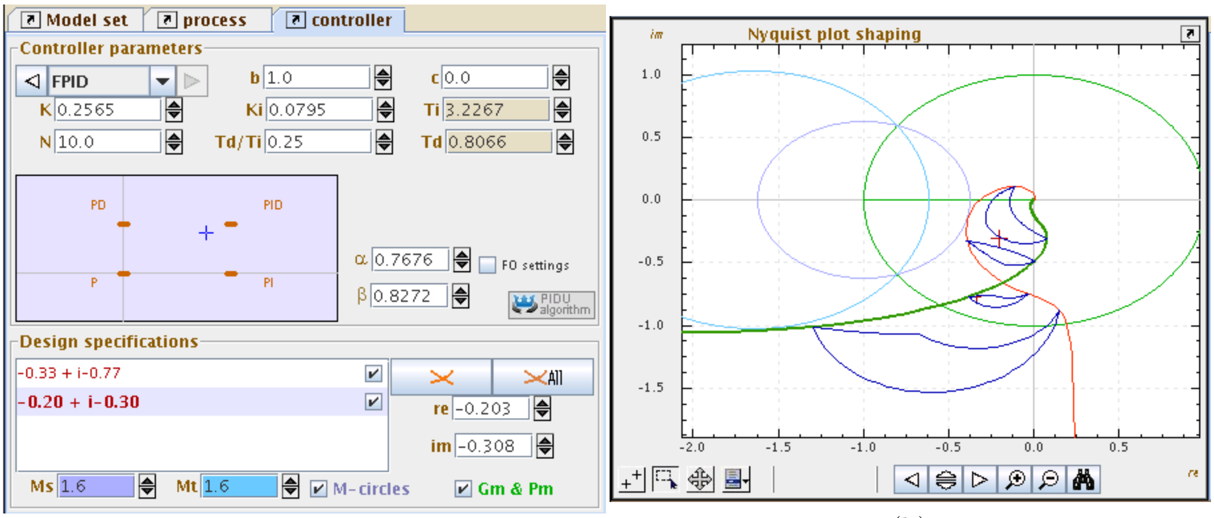


(a)



(b)

Figure 3.5: a) Value set editor tab, b) Custom TF dialog .



(a) (b)

Figure 3.6: a) *Controller* tab, b) *Nyquist plot shaping* panel.

The remaining parameters K, K_i, T_i, T_d, b a c are available after clicking in the robustness regions graph. The T_i and T_d parameters are demarked by another background color because of their dependence on other parameters K, K_i and f.

In the lower part, there is a list of design specifications (Nyquist plot shaping points). By checkboxes below the list, we can show/hide M-circles and unit circle for easy gain and phase margin definition. The values Ms and Mt can be defined precisely. They define the upper limit of sensitivity and complementary sensitivity function, respectively. The drawn *M-circles* define the protected area of Nyquist plot. The shaping points can be added by clicking in the *Nyquist plot shaping graph, SF* or *CSF* graph. The shaping points can be divided as follows:

- *Nyquist plot shaping point*
  - *Phase margin point* (`Pm`) – is created by mouse click on the unit circle – denoted by *Pm*
  - *Gain margin point* (`Gm`) – is created by mouse click on the negative real axis – denoted by *Gm*
  - *General shaping point* – is created by mouse click anywhere else – typically near *M-circles*
- Sensitivity functions shaping points
  - *SF shaping point* (`SF point`) – is created by mouse click in the sensitivity function graph. In the Nyquist plot graph is represented by a circle. Note, that the Nyquist plot should be outside this circle up to the frequency given by the SF shaping point.
  - *CSF shaping point* (`CSF point`) – is created by mouse click in the complementary sensitivity function graph. In the Nyquist plot graph is represented by a circle. Note, that the Nyquist plot should be inside this circle at frequencies higher than the frequency given by the CSF shaping point.

At the right side of the design specification list are buttons that enable deleting of design specifications. There are also input fields, where the location of shaping points can be precised. The meaning of field is changing according to currently selected design specification.

3.4 Frequency responses panel

These graphs are tightly connected with the *Tab panel*. If the *Model set* or *process* tab is active in the TP then the *Process frequency response* graph with value sets of active model sets is shown. The value sets belonging to one frequency are emphasized by thick line. The value set frequencies can be edited comfortably after clicking at the "..." button situated at the right side of the frequencies input field. This frequency values editor is depicted in Fig. 3.5 a.

If the *controller* tab is active one can see here the *Nyquist plot shaping* graph with defined shaping points. When all controller parameters are known – it means after clicking in the robustness regions window – the Nyquist plots of all active processes and also the closed loop value sets are depicted immediately. The shaping points can be added by clicking in this graph.

3.5 Robustness regions panel

Here, the robustness regions in $K - K_I$ plane are drawn. After first click, one can see here also the cross representing the actual K, K_I parameters. The region is added to the graph immediately when a new shaping point is defined. Note, that the best choice of controller K, K_i parameters is point with maximum K_i coordinate in the admissible intersection of robustness regions.

Always, the region corresponding to the currently selected process and design specification is emphasized by thick line. The default region color is inherited from the process color.

The parameter cross can be fixed to the any region by double click on the region border. A locked cross is bordered by a circle. If subsequently the region changes its shape (e.g. the shaping point is dragged) then new optimal parameters with maximum K_I coordinate are set automatically. Unlock can be done via mouse click out of the region border.

3.6 Closed loop performance panel

Here one can switch between following graphs

- *SF* – sensitivity function. The SF shaping point can be defined by mouse click (helps us to dump low frequency disturbances).
- *CSF* – complementary sensitivity function. The CSF shaping point can be defined by mouse click (helps us to reach the proper bandwidth).
- *Si* – input sensitivity function
- *Su* – control sensitivity function
- *Controller* – controller amplitude frequency response
- *Step* – step response of the process
- *CL Step* – closed loop and load disturbance step response

The last two graphs (time simulations) contain in the upper right corner the *Run/Pause/Stop* button, which runs, pauses and stops the simulation. The time simulations are not computed after each controller parameter changes because they are very time-consuming. This behavior can be changed in the *Settings* dialog.

Remind that the time simulations are done in a serial way, e.g. one process after another.

3.7 Interactivity of graphical objects

To minimize the duration of the design procedure, a very high interactivity was build into the applet. While one parameter is changing the other joined characteristics are recomputed immediately.

- *the sample of frequency response (MF1, MF2)*
  - mouse dragging – the value sets for defined frequencies are recomputed immediately.
  - Hide/Color – these procedures are applied on all value sets of this model set
- *shaping point*
  - mouse dragging – the related robustness regions are recomputed automatically.
  - Hide/Delete – these procedures are applied also on all related robustness regions
- *M-circles*
  - mouse dragging – the values M_S or M_T are changing.
- K, K_I *parameter cross in RR graph*
  - mouse dragging – the graphs *Nyquist, SF, CSF, Si, Su* and *Controller* are recomputed automatically
- *The* $\mathrm{PI}^\alpha\mathrm{D}^\beta$ *cross in* α, β *plane*
  - mouse dragging – the graphs *Nyquist, SF, CSF, Si, Su, Controller* and also all robustness regions are recomputed automatically
- Value sets
  - mouse dragging on the object – The frequency of actual value set is shown besides the graph title. Below the process table, one can see the transfer function that generates the actual point on the value set boundary. Such process can be added to the table if mouse button is released.
  - mouse click – Adds the process generating the value set boundary point to the process table.
- Robustness regions
  - mouse dragging on the object – The frequency generating the actual point of the parametric curve is shown besides the panel title. The same frequency is emphasized also in *Nyquist, SF, CSF, Si* and *Su* graph. Notice that the robustness regions generating by SF and CSF shaping points are not parameterized by ω. In the process table and list of design specifications, the items generating the current region are highlighted.
- Graphs *Nyquist, SF, CSF, Si, Su, Step, CL Step*
  - mouse dragging on the object – The frequency and amplitude of the actual point is shown besides the panel title. The corresponding process is selected in the table.

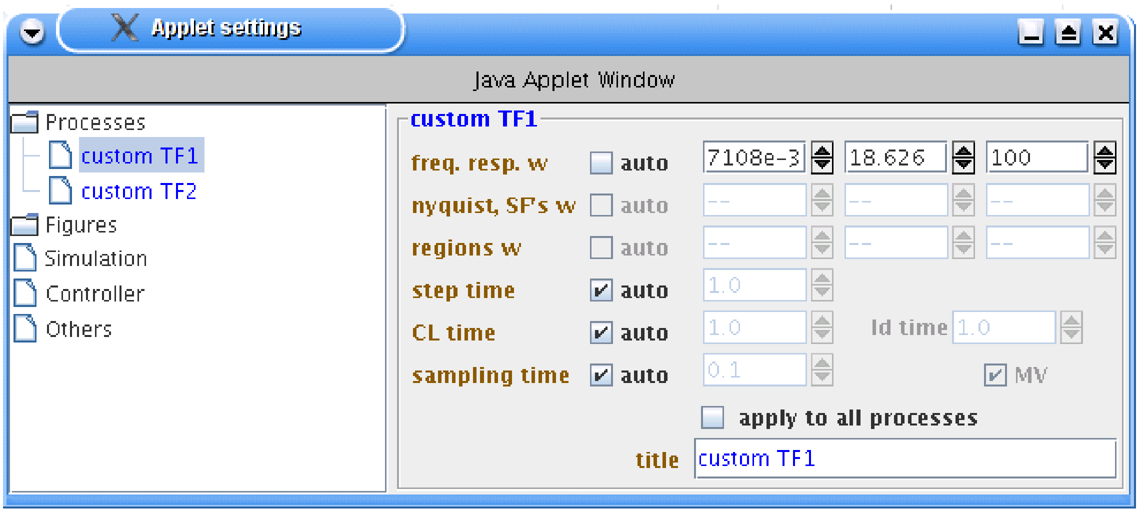


Figure 3.7: *Settings* panel

3.8 Settings dialog

The settings dialog (Fig. 3.7) is activated by the *Setting* button in the lower right corner. In the left part of the panel is the tree with following items:

- *Processes* – The list of processes appears after extraction of this node. For each process one can define (if the *auto* checkbox is unselected)
  - *freq. resp. w* – frequency range for the process frequency response computing and drawing (min ω, max ω, point count)
  - *nyquist, SF's w* – frequency range for Nyquist plot and sensitivity functions computing and drawing (min ω, max ω, point count)
  - *regions w* – frequency range for robustness regions computing and drawing (min ω, max ω, point count)
  - *step time* – process step response simulation time
  - *CL time* – closed loop simulation time
  - *ld time* – simulation time when load disturbance is applied on the process input
  - *sampling time* – sampling time of the process and the controller used for time domain simulations
  - *MV* – defines if for this process also the controller output (manipulation value) is drawn in the graph
  - *apply to all processes* – if the user changes should be applied to all processes
  - *title* – process title

  When the node *Processes* is chosen in the tree then the changes will be applied to all processes. (the text *Apply changes to all processes* is shown in the panel header instead of process title).

  Each process can have its own sampling time.

- *Figures* – The list of all graphs appears after extraction of this node. When a proper graph is selected, the panel equivalent with axes setting dialog is shown. Here one can define axes ranges, locking state, etc.

- *Simulation* – here the additional simulation parameters common for all processes can be changed
  - *Simulate CL when dragged* – the closed loop is simulated immediately when the PID parameter cross in RR graph is moved by mouse dragging.
  - *Simulate CL when clicked* – the closed loop is simulated immediately when the PID parameter cross location in RR graph is changed by mouse click.
  - *Step size* – step size for process step response simulation
  - *CL step size* – reference signal step size for closed loop simulation
  - *CL ld size* – load disturbance step size for closed loop simulation
  - *SP dist A, LD A, PV A* – amplitude of sinusoidal disturbance at reference signal, controller output and process variable, respectively.
  - *SP dist w, LD w, PV w* – frequency of sinusoidal disturbance at reference signal, controller output and process variable, respectively.
- *Controller* – other controller settings used for more realistic simulation
  - *Saturation HI limit* – high saturation limit of the controller output
  - *Saturation LO limit* – low saturation limit of the controller output
  - *Dead zone* – controller dead zone about zero control error
- *Others* – other important settings
  - *vset point num* – point count for computation of one curve of the value set boundary.
  - *frequency unit* – frequency unit used in the whole applet: [Hz] or [rad/s]
  - *angle unit* – angle unit used in the whole applet: [deg] or [rad]
  - *w axes* – sensitivity function frequency axis scale: linear or logarithmic
  - *Confirm "Delete all processes" operation* – if 'delete all processes' operation is necessary to confirm by 'Yes/No dialog'
  - *Confirm "Delete process" operation* – if 'delete process' operation is necessary to confirm by 'Yes/No dialog'
  - *Confirm "Delete all design spec." operation* – if 'Delete all design spec.' operation is necessary to confirm by 'Yes/No dialog'
  - *Confirm "Delete design spec." operation* – if 'Delete design spec.' operation is necessary to confirm by 'Yes/No dialog'

3.9 Applet status line

The status line is situated in the lowest part of the applet If there is no computation currently running the text `Ready` is shown in the status line. During the simulation, the user can see here information about currently simulated process and current simulation time.

4 Error messages

The following error messages can appear during working with the applet:

- `'Wrong number format'` – The text that user typed into the input field cannot be recognized as a number. Allowed formats are for example `-1.25` or `3.74E2`.

- `'Enter three numbers: [MIN] [MAX] [NUMBER OF W]'` – Appears when the value set frequency field is set to log. space and the user has not entered exactly three numbes.
- `'Nyquist plot can not reach this point'` – The shaping point is unreachable, the robustness region is empty. Typically when user wants to put low-order process Nyquist plot into higher quadrants.
- `'The moment model set is empty'` – The process satisfying these three numbers does not exist.
- `'deg(num) >= deg(den) in Transfer function'` – The order of numerator must be strictly less than the order of denominator.
- `'Numerator not defined!'` – The numerator input field is empty.
- `'Denominator not defined!'` – The denominator input field is empty.
- `'Transport delay must be positive!'` – The user has defined a negative transport delay.
- `'Frequencies must be positive!'` – The user has defined values set frequencies must be positive.
- `'Out of memory! Too large buffer for delay simulation'` – Too large transport delay when comparing to the sampling time. Java cannot allocate such large buffer for simulation.
- `'Coeffs. in fractional operator approximation are Inf or NaN'` – The realization of fractional order process or controller cannot be done. The simulation results are not valid.

5 Typical problems and questions

The time simulations seems not to be valid
: Try to change the sampling time for simulation in according to time constants of the process and controller.

The frequency responses are not shown correctly
: Try to change the frequency range of the process freq. response or Nyquist plot and SF's, respectivelly.

Some robustness regions are not shown or are shown only partially
: Try to change the frequency range for robustness regions.

The load disturbance step is not done for all processes at the same time
: The LD step time is chosen automatically during the simulation when a process is reaching a steady state. You can define your own step time and apply it to all processes.

Note that all of above mentioned actions can be done in Settings dialog.

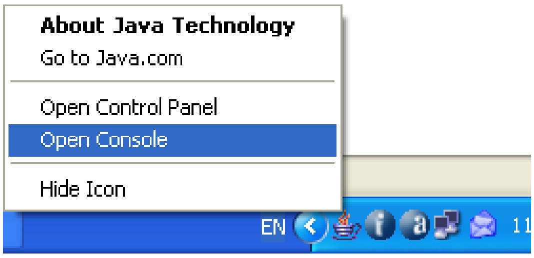


Figure 6.8: How to open the Java console

6 What to do when in trouble?

If the applet does anything strange or is without response please contact us using PIDlab web page or use e-mail **pidlab@pidlab.com**. To solve the problem quickly and effectively, important information for us is:

- brief description of the problem
- if the problem is reproducible, the shortest way to reach the problematic state after the applet is started and initialized
- applet version and build no. (is in the applet title, e.g. version 1.2 .07)
- version of the Java Virtual Machine
- copy of the Java console, if any Exceptions (error messages) appeared there.

Note that in Windows XP, the Java version and also the Java console can be found after clicking at the 'cup of coffee' Java icon in the main tool panel (see Fig. 6.8).

You may also find answers to most common question in PIDlab FAQ section.