PROJECT MEMO

SINTEF
Electronics and Cybernetics

Automatic Control
Address: N-7034 Trondheim, NORWAY
Location: O.S.Bragstads plass 8, NTH
Phone: +47 73 59 43 75
Fax: +47 73 59 43 99

Enterprise no.: 948007029

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MultiTune

- user description

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AUTHOR	NUMBER OF PAGES
Tor Steinar Schei	9

This memo contains a user description for MultiTune, which is a software tool for automatic tuning of conventional control systems including PID controllers, feedforward and decoupling elements.

MultiTune

Automatic tuning of PID controllers with feedforward and decoupling elements

About MultiTune

MultiTune is a software tool for automatic tuning of industrial process control systems consisting of *PID controllers,* with possible *feedforward* connections from measurable disturbances and *decoupling* between control loops. The PID controllers might be operating in *single loops* or as *cascade* controllers.

MultiTune is used both for initial tuning of a control system as well as for later retuning of the system during normal process operation. The preferred use of MultiTune, which will lead to the most accurate tuning, is to tune the individual control loops during normal closed loop operation. Hence, all controllers should, if possible, be set to automatic mode during tuning. The current control loop, which is to be tuned, is excited by varying the controller setpoint in steps around a nominal value, following a specified pattern (this nominal value might be time varying during tuning of the inner loop of a cascade where the outer loop is operating in automatic mode). Process input and corresponding output measurement are logged on file for later analysis. The analysis is performed by the program MultiTune, which reads the time series from file and computes the process *transfer function* from control input to output measurement. The PID (or PI) control parameters are determined from an *optimization.* The computed control parameters are transferred manually to the PID controller.

The entire control system can be tuned by tuning the individual controllers sequentially, loop by loop, as described above. It is an advantage with MultiTune that the individual controllers can be tuned during normal operation without transferring the controllers to manual mode. However, in the case where an initial feasible set of control parameters do not exist, an initial tuning is performed in open loop, that is with the controller in manual mode. In this case the control signal (process input) from the controller is varied in steps around a nominal value, following a specified pattern. Process input and output measurement are logged on file and analyzed as described above. After this initial tuning the controller is transferred to automatic mode, and preferentially retuned in closed loop as described above.

MultiTune is also used for tuning of decoupling elements between individual control loops, and for tuning of feedforward elements from measurable disturbances. It is then a requirement that the feedforward variables can be excited during the tuning experiment, either directly or indirectly.

MultiExcite

As described above the tuning is performed in two phases. First, the current control loop is excited and a time series with process input and output measurement is logged on file. Second, the control parameters are determined from an off-line analysis and optimization. In order to attain an optimal tuning it is essential that the control loops are properly excited such that the process dynamics which is most important for control system performance can be identified with high accuracy. This is assured by the use of excitation methods which automatically adjust the frequency of the excitation signal in accordance with the process dynamics.

The excitations are generated by *MultiExcite*, which is a separate software module integrated with the process control system. During excitations, MultiExcite communicates with the current controller that is to be tuned. The logging of time series to files is also controlled by MultiExcite.

In advance of the tuning MultiExcite is initialized with the following information:

- Tag number (-s) for the loop (-s) which should be excited.
- File name.
- Choice of excitation mode (see below).
- Parameters which determine the excitation amplitudes (steps in controller setpoint or process input). The duration of each step is determined automatically by MultiExcite.
- Parameters which determine the total number of steps in controller setpoint or process input. These parameters are given default values.

The user must choose between three excitation modes:

1. *Open loop* tuning of PID controller. Hence, the controller is set to manual mode. The excitations are performed by varying the control signal (process input) in steps around a nominal value. The amplitude of the steps is set by the user.
2. *Closed loop* tuning of PID controller. Hence, the controller is set to automatic mode. The excitations are performed by varying the controller setpoint in steps around a nominal value. The amplitude of the steps is set by the user.
3. Tuning of *feedforward/decoupling* element. Decoupling between control loops is attained by implementing a feedforward connection from the process input for one control loop to the feedforward terminal for an other controller which interacts with the first one. The feedforward element can be a static or dynamic. This system is excited similarly as for mode 1 or 2 (see below).

Example: use of MultiExcite

Consider the simple block diagram for a system with two PID controllers in Figure 1. The process is represented by the blocks P_{11}, P_{21}, P_{12} and P_{22}, which models the influence of the two control signals (process inputs) U_1 and U_2 on the output measurements PV_1 and PV_2. A possible decoupling between the two loops is represented by the blocks FF_{12} and FF_{21}. It is often sufficient to use only one (or none) of these blocks, depending on the strength and characteristics of the blocks P_{21} and P_{12}, representing the process couplings between the two loops.

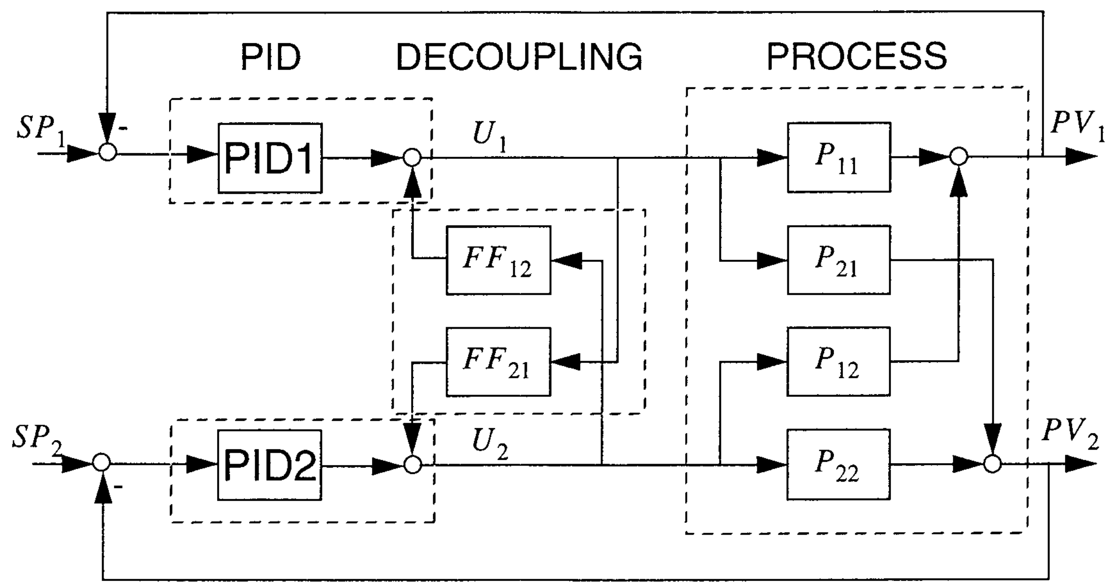

Figure 1 Block diagram for control system with two process inputs (U_1 and U_2) and two output measurements (PV_1 and PV_2). Decoupling between the two loops is attained by using one or both feedforward blocks FF_{12} and FF_{21}.

Initial tuning of the PID controllers in Figure 1 is performed in open loop (mode 1). There is no initial decoupling between the loops. The process input for one of the control loops (e.g. U_1) is excited as shown in Figure 2. The amplitude of the steps (e.g. 10%) is chosen by the user, the length of each step is determined automatically by MultiExcite. The process input (U_1) and output measurement (PV_1) is logged to file, and optimal control parameters are then computed by MultiTune. PID1 can now by set to automatic mode.

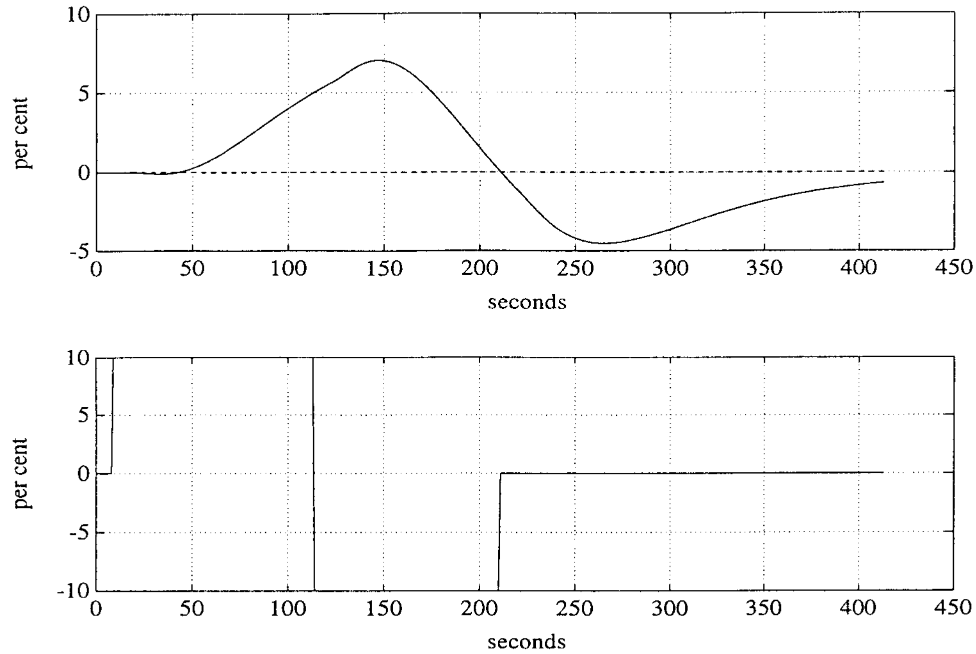

Figure 2 Open loop tuning: The upper plot shows the output measurement (PV_1), the lower plot shows the process input (U_1).

The same procedure is followed for the tuning of PID2. Due to coupling between the two loops it might be necessary to retune the first loop (PID1) after PID2 has been tuned and set to automatic mode. This is preferentially done with both controllers in automatic mode (closed loop tuning). The setpoint SP_1 is excited in steps as shown in Figure 3. The amplitude of the steps (e.g. 3%) is chosen by the user, the length of each step is determined automatically by MultiExcite. The excitation sequence is composed of two parts; In the first part the setpoint is varied with a relatively high frequency, in the second part the length of each step is longer. This excitation sequence ensures that the process dynamics can be identified with high accuracy in the frequency range around the *bandwidth* of the control loop. The high frequency oscillations correspond to the *critical frequency* for the control loop, the low frequency oscillations approximately correspond to the *crossover frequency.* Hence, the excitation sequence is very favorable with respect to obtaining accurate controller tuning. This excitation method is unique, and it is not used by other autotuners in the market.

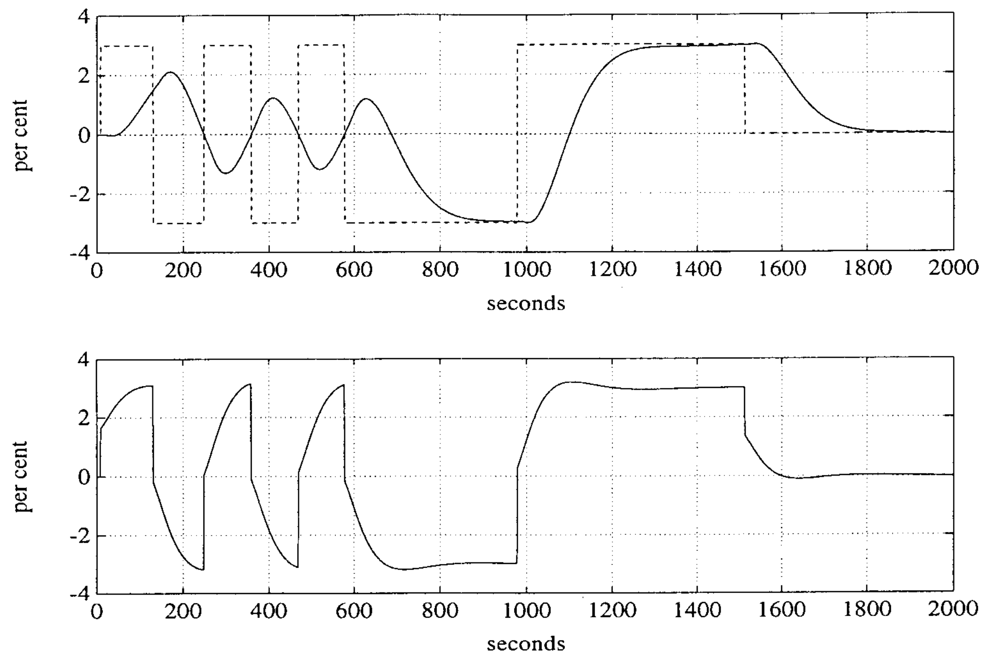

Figure 3 Closed loop tuning: The upper plot shows the setpoint (SP_1, dashed line) and the output measurement (PV_1, solid line). The lower plot shows the process input (U_1).

If there is considerable interaction between the two control loops, the performance might be improved by tuning one of the two feedforward elements in Figure 1. There is assumed to be considerable interaction from the process input U_2 to the output measurement PV_1. It will then be favorable to use the feedforward element FF_{12}. The excitation sequence used for tuning this feedforward element is shown in Figure 4.

In the first part of the excitation sequence the setpoint SP_1 is varied in steps as shown in the upper plot in Figure 4. The frequency of this excitation is above the critical frequency and below the crossover frequency for loop no. 1. In the second part of the excitation sequence the setpoint for the other loop, SP_2, is varied in steps, similarly as for SP_1. SP_2 is not shown in the figure but the influence on the output measurement PV_1 and the process input U_1 is shown in the second half of the time series in Figure 4. The time series for U_1, U_2 and PV_1 are used by MultiTune to determine the parameters of the feedforward element FF_{12}. The feedforward element consists of a gain, and optionally a first order lag and a delay.

In the case of strong coupling between the process input U_1 and the process output PV_2 the control performance might be further improved by tuning the feedforward element FF_{21}. This element is tuned similarly as FF_{12}. It is, however, often sufficient to use only one of the two feedforward elements in Figure 1, depending on the strength and characteristics of the cross couplings P_{12} and P_{21}.

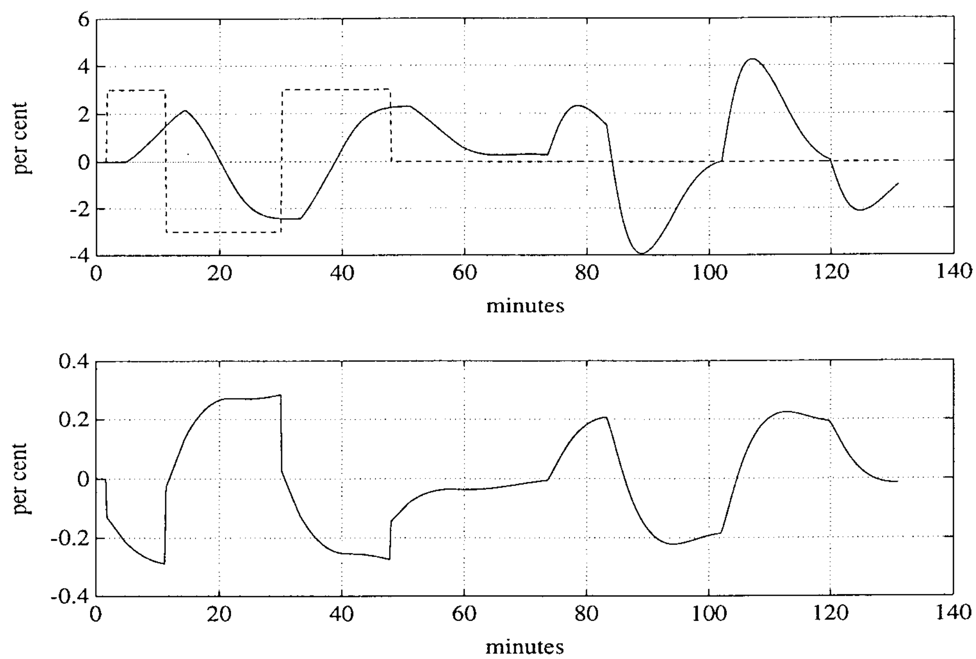

Figure 4 Tuning of FF_{12}: The upper plot shows the setpoint SP_1 (dashed line) and the output measurement PV_1. The lower plot shows the process input U_1.

Analysis and optimization with MultiTune

After finishing an excitation sequence optimal PID or feedforward parameters are computed, depending on which excitation mode has been used. The software tool MultiTune, with a graphical user interface as shown in Figure 5, is used for this purpose. The analysis starts by reading the proper time series from file. The relevant process models in Figure 1 are then identified. This procedure includes proper filtering of the input and output data prior to transfer function identification. The transfer function models P_{11} and P_{22} are identified for computation of the control parameters for PID1 and PID2 respectively. In order to compute the feedforward element FF_{12} the models P_{11} and P_{12} are identified.

The time series read by MultiTune can be plotted as shown in Figure 5. A simulation with the identified model might also be performed, with the purpose of comparing the simulation output with the real output measurements. In addition several control engineering diagrams, e.g Bode and Nyquist diagrams, might also be plotted.

The PID parameters are determined from an *optimization*. The user specifies maximum amplitude values for the *sensitivity function* and the *tracking ratio* for the control loop. These parameters, which are closely related to the *gain* and the *phase margins*, specify the compromise between fast closed loop response and the required degree of stability and robustness.

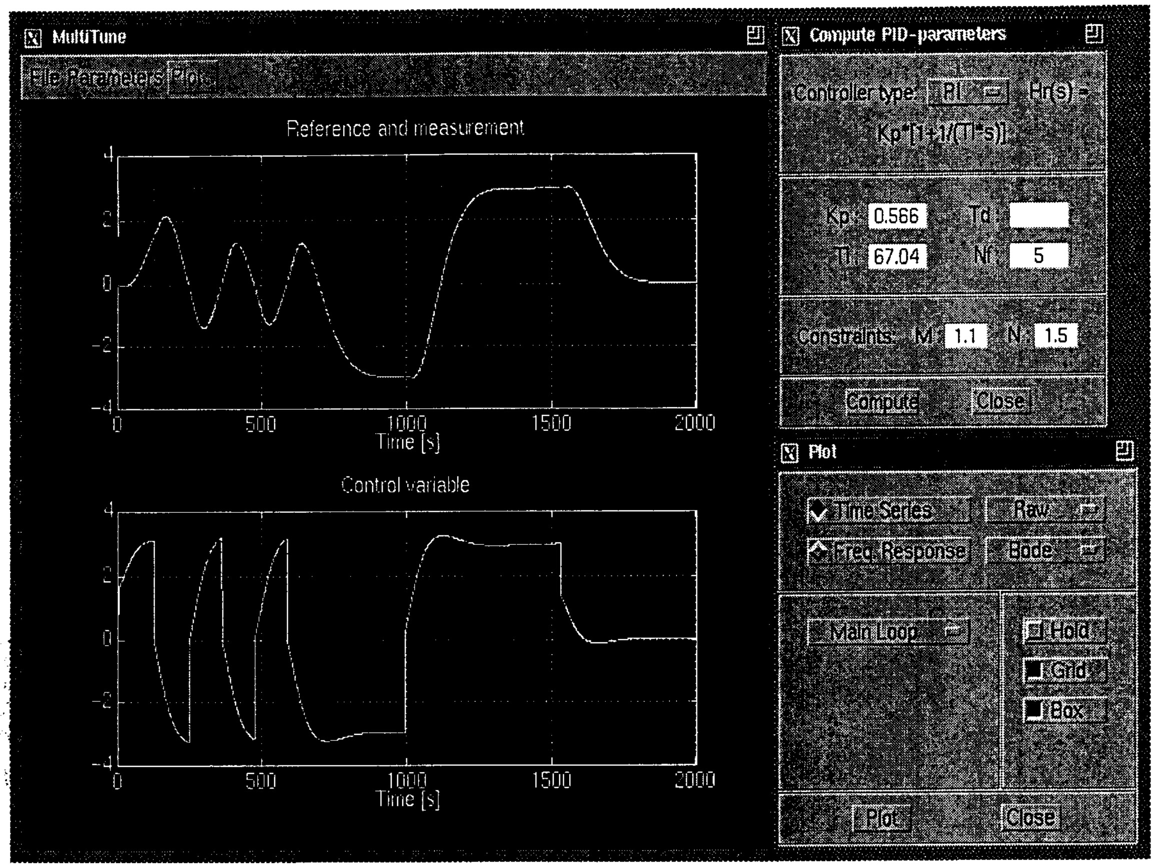

Figure 5 User interface for MultiTune.

Optimal feedforward parameters are computed by opening a new window, similar to the upper and right window in Figure 5 which is used for computation of the PID parameters.

After the computed PID or feedforward parameters have been transferred to the control system, new loops can be tuned, following a sequential procedure.

References

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T. S. Schei, "Automatic tuning of simple decouplers in multivariable control systems," *Proc. IFAC World Congress*, Sydney, Australia, 1993.

For more information

MultiTune is developed at SINTEF Automatic control. For more information or a demonstration, contact:

SINTEF Electronics and cybernetics, Automatic control
att. Tor Steinar Schei or Ivar Halvorsen
7034 Trondheim - NTH
Tlf. 73 59 43 75