

PIDDESIGN– Software for PID Control Education

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Abstract: The aim of this paper is to present the software *PIDDESIGN*. The software has been developed using MATLAB – Simulink programming environment and uses its graphical user interface to make software more interactive and user friendly. The software represents useful tool for simple step-response-based identification of a controlled process, fast PID controller tuning using various methods and effective evaluation of control performance using simulation of control. The software enables to focus the attention on control performance analysis to increase the quality of control. The properties of the software determine its application especially for educational purposes.

Keywords: PID control, controller tuning, step-response, identification, control performance, filtration, control education

1. INTRODUCTION

PID controllers belong to the most used types of feedback controllers in industry due to the structural simplicity, robustness, not demanding design and ease of implementation (Åström and Hägglund (2004)), (Åström and Hägglund (2001)), (Karasakal et al. (2011)), (Vrančić et al. (2010)), (Toscano and Lyonnet (2009)), (Shen (2002)), (Panda (2009)). Considering the feedback control scenario, PID controllers should be tried as the first solution, because they are suitable for effective control of wide range of processes (Åström and Hägglund (2001)). Increased implementation of model predictive control often requires well tuned PID controllers at the basic level to manage fast interactions (Åström and Hägglund (2001)). If the feedback is used, there is a threat that the closed-loop system will become unstable (Åström and Hägglund (2001)). Hence, the primary requirements on feedback control are stability, robustness and simple handling (Åström and Hägglund (2001)). Therefore, it is important to acquire well this domain by engineering handling.

PID control strategy should be comprehended as a considerable part in the education oriented on process control. Suitable software application is able to contribute to increasing the quality of education and better understanding the PID control. There exist various software applications, which enable the PID controller design, for example see (The MathWorks (2011b)), (The MathWorks (2011a)), (Flores (2000)), (ExperTune (2011)), (Lošonský (2006)), (Schlegel and Čech (2004)) or (Závacká (2011)).

The aim of this paper is to present the software *PIDDESIGN*, previously called *PIDTOOL* (Oravec and Bakošová (2011)), (Čemanová (2007)). The software has been renamed because of the name duplicity with MATLAB interactive GUI (The MathWorks (2011b)). The *PIDDESIGN*

enables to identify the controlled process model from its step response, to design simple PID controller and to evaluate the quality using simulation of control. The software is focused mainly on PID controller tuning and can be used by everybody who needs to tune PID controllers or wants to compare various types of control algorithms with simple PID control strategy. The software enables to focus attention on control performance analysis to increase the quality of control. The software is intended for educational purposes and the MATLAB environment has been chosen for its design as MATLAB is widely used at FCFT STU in Bratislava. The developed software has been tested by students in two courses; in the course Process Dynamics and Control that is taught in the first year of the Master study and the course Integrated Control in the Process Industry that is taught in the third year of the Bachelor study. The *PIDDESIGN* enables to simplify the PID controller design and to finish prescribed tasks in the given time. The software is going to be released at kirp.chtf.stuba.sk/sw/redmine/projects/piddesign. Until that, it is possible to contact the authors to obtain the software.

2. THE SOFTWARE *PIDDESIGN*

The software *PIDDESIGN* has been developed at the Institute of Information Engineering, Automation, and Mathematics at the FCFT STU in Bratislava (Oravec and Bakošová (2011)), (Čemanová (2007)) in the MATLAB R13 v7.0 and Simulink v6.4 programming environment. The software is compatible with wide scale of newer versions of MATLAB–Simulink. The software uses MATLAB graphic user interface (GUI) to determine the *PIDDESIGN* as visual and user friendly tool. Many parameters have preset values to make work more comfortable. It is easy to change a language of graphic user interface to

make software more understandable. Actually, there is a possibility to choose between English and Slovak language. Other languages can be simply added to extend the library of supported languages.

The software *PIDDESIGN* represents useful tool for simple step-response-based identification of a controlled process, fast PID controller tuning using various methods and effective evaluation of control performance using simulation of control. All of these tasks can be solved independently.

If a transfer function of the controlled process is unknown, the software enables to identify the controlled process from its step response. The Strejc method (Mikleš and Fikar (2007)), (Lošonský (2006)) is applied for identification from the aperiodic step response and the method described in (Mikleš and Fikar (2007)) is used for identification from the damped periodic step response. The identified process model can be described as the transfer function (1) for aperiodic or (2) for damped periodic step response

$$G_S(s) = \frac{K}{(Ts + 1)^n} e^{-Ds} \quad (1)$$

$$G_S(s) = \frac{K}{T^2s^2 + 2\xi Ts + 1} e^{-Ds} \quad (2)$$

where n is the order of the system, K is the gain, T represents the time constant, ξ is the damping coefficient, D represents the time delay.

There are three main possibilities for identification. The first one enables to identify the controlled process directly from data obtained from the measured and recorded step response. The second possibility is to run identification from the data stored in an external data file. If noisy step-response data have been loaded, the software enables to run filtration. The third possibility enables to identify process model with required properties of the transfer function, e.g. the order n , to make the process model more tractable or to increase the scale of suitable PID controller tuning algorithms.

The software *PIDDESIGN* is oriented mainly on PID controller tuning. The software enables to tune PID controllers using various analytical and experimental methods, for example see (O'Dwyer (2009)), (Xue and Chen (2008)), (Arousi et al. (2008)), (Åström and Hägglund (1995)), (Mikleš and Fikar (2007)), (Lošonský (2006)), (Weng et al. (1995)), (Shaw (2006)). It is possible to design P, PI, PID or PD controllers. If the zero offset is not required or the process model contains the integrator, the integral part can be omitted (Åström and Hägglund (2001)). If the time delay D is relatively large subject to the model time constant T , or if the controlled process is described by the first order model, the derivative part can be omitted (Åström and Hägglund (2001)).

Control performance obtained using various tuned controllers can be simply compared using simulation of control in different conditions of input constraints, various values of set-point, disturbance, integral windup elimination parameter, and in presence of the uncertainties in the controlled model. The reached quality of control can be judged by eleven evaluated values of quality criteria in the time domain, such as settling time t_S , maximal overshoot

σ_{max} and various integral quality criteria, such as IAE, ISE, ITAE, ITSE and the others (Mikleš and Fikar (2007)), (Xue and Chen (2008)). The displayed figures of control performance and associated control inputs generated by the designed controller, together with the values of quality criteria help to decide, which controller is the most suitable for control.



Fig. 1. Basic window of software *PIDDESIGN*

Values of all parameters, which are necessary for simulation and quality evaluation are stored by *PIDDESIGN*. These stored data can be simply shown by using *Setup/Show results* located in the menu of basic window (Fig. 1). The stored data are transformed into *html*-file. The stored data are shown in simple summary table with date and time of simulation. This ability can be helpful in the case, when many simulations at different conditions have been evaluated and user wants to analyse the influence of them on control performance.

3. EXAMPLE OF APPLICATION OF *PIDDESIGN*

Properties and possibilities of the software will be presented using an illustrative example. The software *PIDDESIGN* generates various figures to show the influence of every user's step in visual and understandable way. To simplify screen-shots of the plots generated by the software, the modified figures have been exported using MATLAB programming environment and placed into this paper.

3.1 The problem formulation

Consider the unknown process model to be controlled. The data file containing the measured data of several process step-responses has been obtained (Fig. 2). A suitable PID controller has to be tuned. In the Command Window of MATLAB programming environment, the *PIDDESIGN* is started by typing *piddesign*. Then the main window is opened (Fig. 1).

3.2 Initial data processing

Using the button *Identification* (Fig. 1) enables to find out required data file in a comfortable way. Normalization of loaded step-response data is automatically executed by *PIDDESIGN* software. Normalized outputs $y_N(t)$ and calculated nominal step response $y_{N0}(t)$ are displayed in the new figure (Fig. 3). In the Figure 3, it is seen that the nominal step response $y_{N0}(t)$ is noisy and damped periodic one. The window shown in Figure 4 enables to run filtration and identification of the loaded data. As the data are noisy, it is useful to use button *Filtration* at first.

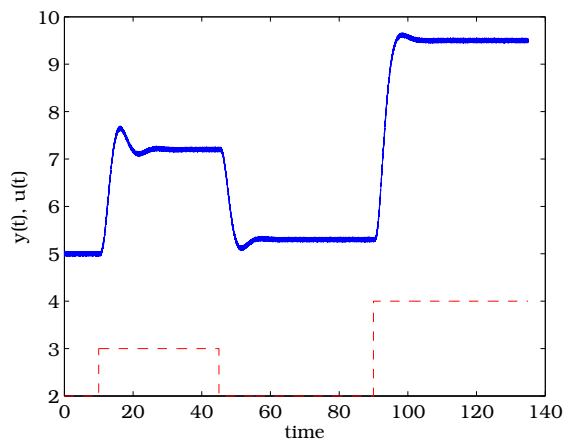


Fig. 2. Loaded data file – measured output variable $y(t)$ (solid) and associated control input $u(t)$ (dashed)

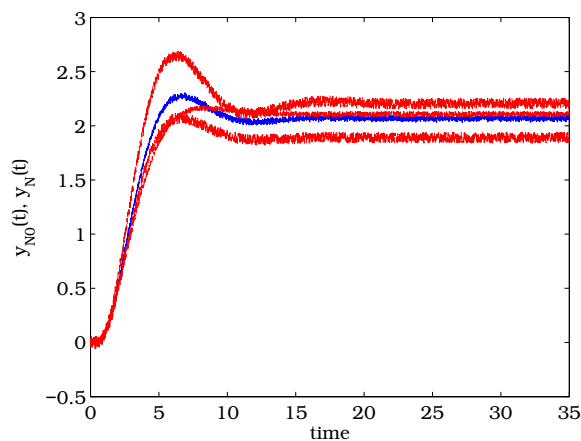


Fig. 3. Normalized step responses $y_N(t)$ (red) and nominal step response $y_{N0}(t)$ (blue)



Fig. 4. Choice of processing of loaded data

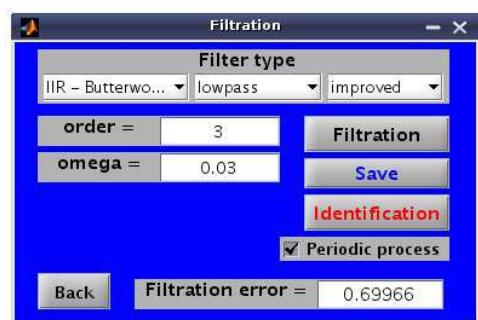


Fig. 5. Window for setting the filtration parameters

3.3 Filtration

The new window for filtration is opened (Fig. 5). The irrecurisive *Butterworth* low-pass 3rd order filter with filter frequency $\omega = 0.03$ (Kugelstadt (2008)) has been applied to reduce the noise of loaded data (Fig. 6). If the quality of filtration is satisfying, the reached filtered data can be simply stored into the new data file for later usage pressing the button *Save* (Fig. 5). After filtration, identification can start.

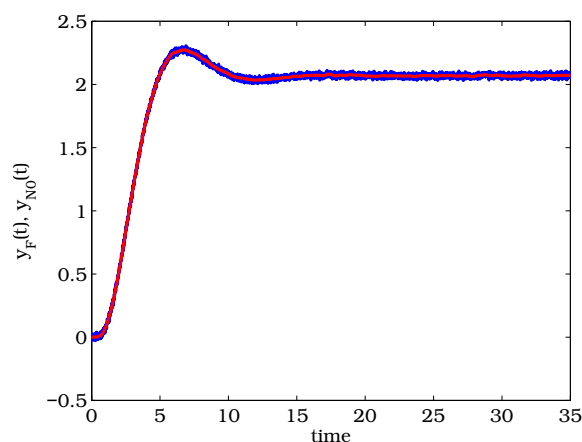


Fig. 6. Comparison of the filtered step response $y_F(t)$ (red) and the nominal step response $y_{N0}(t)$ (blue)

3.4 Identification

When the damping step response is going to be identified, the check-box *Periodic process* has to be activated before using button *Identification* (Fig. 4), (Fig. 5). Calculated parameters of the identified process model (2) are given in the transfer function

$$G_S(s) = \frac{2.0727}{1.3266^2 s^2 + 2 \times 0.5831 \times 1.3266 s + 1} e^{-0.34s} \quad (3)$$

and the identification error $E_{ID} = 4.5326 \times 10^{-3}$ has been evaluated by the software using the formula

$$E_{ID} = \frac{\int (y_{N0}(t) - y_{ID}(t))^2 dt}{\int y_{N0}(t)^2 dt} \quad (4)$$

where $y_{ID}(t)$ is the step response of identified model.

Comparison of the step response of the identified model $y_{ID}(t)$ and the nominal filtered step response $y_F(t)$ is shown (Fig. 7).

3.5 Approximation using the aperiodic model

The software *PIDDESIGN* enables to approximate damped periodic model (2) using the identification by Strejc method (Mikleš and Fikar (2007)) to obtain aperiodic model (1). This ability of the software enables to apply wide scale of controller tuning methods based on controlled process model in the form (1). To run approximation, user can use the button *Identification* in the Fig. 4 with the inactive check-box *Periodic process*. Then using the possibility of *Identification Tuning*, user can receive the transfer

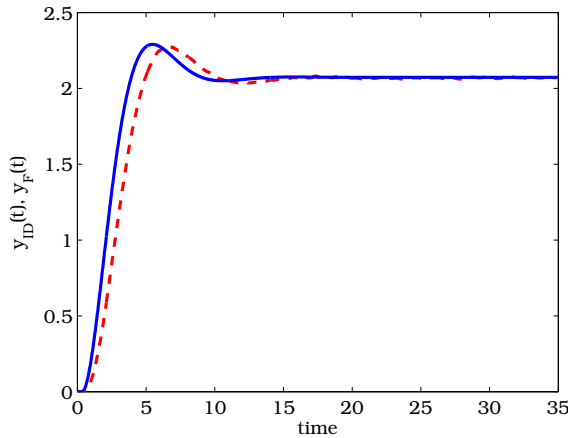


Fig. 7. Comparison of the step response of the identified model $y_{ID}(t)$ (solid) and the filtered step response $y_{N0}(t)$ (dashed)

function, which generates the step response, that covers the original one more precisely (Fig. 8). The step response of identified transfer function can be simply modified by changing the slope of its tangent (Lošonský (2006)). The difference between the original step response and the step response obtained by the identification using the modified position of tangent is directly displayed as a red area in the new window (Fig. 9). This ability of the software enables to check the quality of identification in a visual way. In this window, the calculated value of identification error is also shown. The background color changes according to the value of E_{ID} . If the value of E_{ID} has increased, red color is shown. If the identification precision has increased, the green color is displayed (Fig. 9).

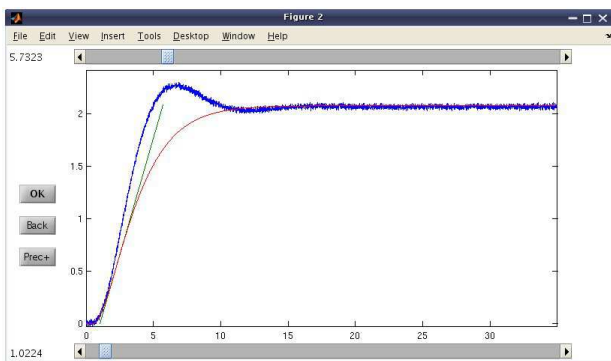


Fig. 8. Window for step-response-based aperiodic identification tuning, based on changing the slope of tangent

Chosen parameters of the approximated process model (1) are given in the transfer function (5)

$$\tilde{G}_S(s) = \frac{2.0793}{(1.7332s + 1)^2} e^{-0.5326s} \quad (5)$$

and the approximation error value is $\bar{E}_{ID} = 9.0365 \times 10^{-3}$.

3.6 PID controller tuning

When the process model is obtained in required form (1) or (2), the PID controller can be designed using the button *Controller Tuning* (Fig. 1). The new window is opened

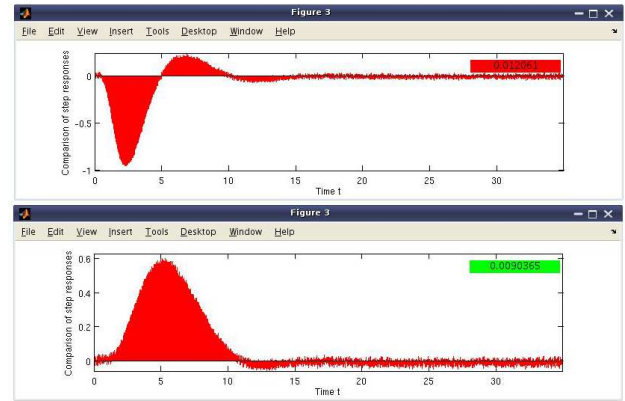


Fig. 9. Window showing difference between the original step response and the modified step response: before identification tuning (upper) and after identification tuning (bottom)

(Fig. 10) where the user can choose a required type of PID controller and a type of a tuning method.

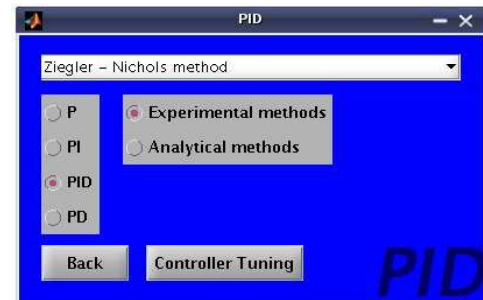


Fig. 10. Window for PID controller tuning

Six PID controllers have been designed for the identified system. The controllers $G_{R1} - G_{R3}$ has been tuned using analytical methods and controllers $G_{R4} - G_{R6}$ using experimental methods. The controller $G_{R1} - G_{R2}$ tuning was based on damped periodic process model G_S in the form (3) and the controller $G_{R3} - G_{R6}$ tuning used approximated aperiodic process model \tilde{G}_S in the form (5). The controller G_{R1} has been tuned using the *pole placement method* (Mikleš and Fikar (2007)) using *binomic* reference polynomial with set pole $\omega_P = -0.8$ and the controller G_{R2} has been tuned using the *pole placement method* (Mikleš and Fikar (2007)), using *minimum $t_{5\%}$* reference polynomial with set pole $\omega_P = -0.8$. The controller G_{R3} has been designed using *the method based on phase and gain margin* (Weng et al. (1995)) using the values of gain margin $G_M = 4$ dB and phase margin $P_M = 60$ deg. The controller G_{R4} has been tuned using the *Kohen T-sum method* (Arousi et al. (2008)). The controller G_{R5} has been designed using the *Aström - Hägglund method* (Åström and Hägglund (1995)) using the parameter of sensitivity function $M_S = 1.4$ and the weighting parameter of proportional part $b_W = 1$. The controller G_{R6} has been tuned using the *Half damping method* (Lošonský (2006)). The controller design information are summarized in Tab. 1, where Z_R represents the gain, T_I is the reset time and T_D represents the derivative time of the PID controller.

Table 1. The designed PID controllers

Controller	Z_R	T_I	T_D
G_{R1}	1.5553	3.5777	0.5683
G_{R2}	0.5704	1.3121	0.6921
G_{R3}	0.6009	1.4182	1.7332
G_{R4}	0.4809	2.2878	0.5789
G_{R5}	2.3736	3.2556	0.7477
G_{R6}	0.1544	1.1289	0.4028

3.7 Control performance evaluation

Evaluated parameters of the tuned controller G_{R1} are shown in the new window (Fig. 11). In the top right part of the opened window, the parameters of the transfer function of the controlled process are shown. The model G_S for simulation of control was assumed in the form (3). These parameters can be modified and the tuned controller can be so tested in the presence of model uncertainty. The properties of the closed loop with the tuned controller can be judged by simulation of control. The considered control precision has been set as $\delta = 5\%$. Using the button *Step Response* (Fig. 11) starts quality evaluation of control using simulation. The control performances obtained using tuned PID controllers $G_{R1} - G_{R6}$ has been judged from the analytical and visual viewpoints. Various quality criteria in the time domain (settling time t_S , maximal overshoot σ_{max} [%]) and integral criteria (ISE, ITSE, ISE(du)) have been evaluated for every controller (Tab. 2) to do analytical analysis of the quality of control according to the settling time t_S , controlled output $y(t)$ and control input $u(t)$. Figures 12–15 have been generated to analyse the control performance in visual way.



Fig. 11. Window for evaluating the quality using simulation of control

As can be seen in the Table 2, the controller G_{R1} is the best according to the settling time t_S and controlled output. On the other hand the controllers G_{R5} , G_{R6} should be suitable if the restrictions on overshoot would be required. If the control input represents high cost medium, the controller G_{R4} should be used.

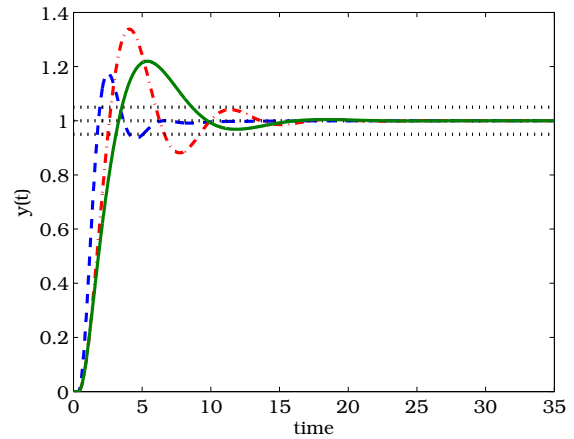


Fig. 12. Control performances assured by controllers designed using analytical methods – G_{R1} (dashed), G_{R2} (dashdotted), G_{R3} (solid)

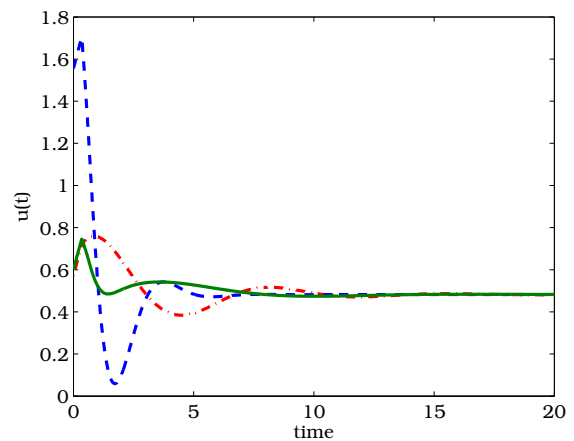


Fig. 13. Control inputs generated by controllers designed using analytical methods – G_{R1} (dashed), G_{R2} (dashdotted), G_{R3} (solid)

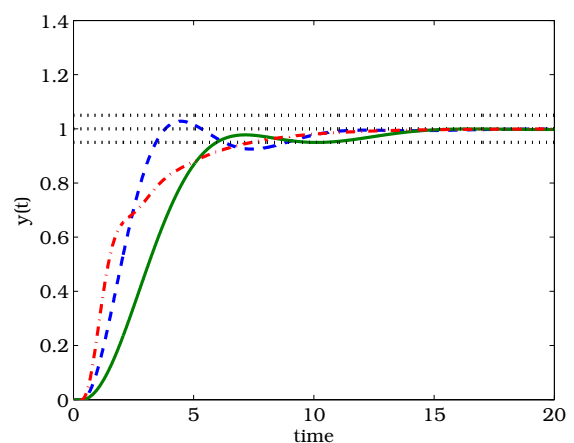


Fig. 14. Control performances assured by controllers designed using experimental methods – G_{R4} (dashed), G_{R5} (dashdotted), G_{R6} (solid)

Table 2. Control performance criteria

Controller	t_S	σ_{max}	ISE	ITSE	ISE(du)
G_{R1}	5.5	17.6	1.0	0.7	6.4
G_{R2}	9.2	33.8	1.6	6.8	1.7
G_{R3}	8.6	22.0	1.6	6.7	2.5
G_{R4}	8.7	2.8	1.6	2.8	1.6
G_{R5}	7.4	0.0	1.3	3.2	10.0
G_{R6}	10.4	0.0	2.4	8.9	2.6

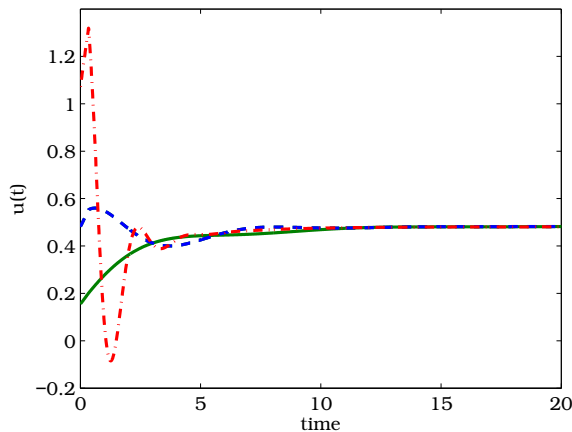


Fig. 15. Control inputs generated by controllers designed using experimental methods – G_{R4} (dashed), G_{R5} (dashdotted), G_{R6} (solid)

4. CONCLUSIONS

The software *PIDDESIGN* is presented in the paper. Some of the software abilities are demonstrated using an illustrative example. The software can be successfully implemented into the education courses oriented on process control. *PIDDESIGN* reduces the time necessary for PID controller design and permits to solve more complicated tasks in process control design.

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