IMPLEMENTATION OF MODIFIED SMITH PREDICTORS INTO A MATLAB PROGRAM

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ABSTRACT

The main aim of the paper is to present a Matlab program for control of time-delay systems using three various modifications of Smith predictor. The software implementation includes the modification for unstable and integrating processes, PI-PD modification for systems with long dead time, and modification applying control design by Coefficient Diagram Method (CDM). The freely downloadable program offers appropriate computational and simulation capabilities accompanied by a simple Graphical User Interface (GUI). Its application potential is illustrated on two control examples.

INTRODUCTION

The time-delay has been intensively investigated phenomenon during the last decades (Richard 2003), because it is very common in many process control applications and its presence in a control loop always brings serious complications. The relatively effective tool for compensation of time-delay term represents the classical Smith predictor which has been known to automation community since 1959 (Smith). However, this control structure has also its disadvantages and limitations.

Some drawbacks of the Smith predictor have been eliminated by improving the idea and creating many modifications of this connection (Watanabe and Ito 1981; Åström et al. 1994; Mataušek and Micić 1996; Majhi and Atherton 1998; Kaya and Atherton 1999; Hamamci et al. 2001; Liu et al. 2005). Furthermore, several of them have been applied also to other problems, e.g. to control of systems with time-varying delay (Matušů and Prokop 2010a; Matušů and Prokop 2011).

This contribution does not intent to bring any novel theoretical aspects of time-delay systems control. Its main aim is to describe facilities of a freely downloadable Matlab environment for control of time-delay systems using three selected modifications of Smith Predictor (Matušů and Prokop 2010b; Matušů and Prokop 2010c). The program is a translated version of the one created under the scope of the Master's Theses (Matušů 2002). More specifically, the software contains:

- Modified Smith predictor for unstable and integrating processes (Majhi and Atherton 1998).
- Modified PI-PD Smith predictor for systems with long dead time (Kaya and Atherton 1999).
- Modified Smith predictor design by Coefficient Diagram Method (CDM) (Hamamci et al. 2001).

Moreover, the paper illustrates the program capabilities also through two control examples.

The paper is organized as follows. In Section 2, the basic theoretical background of implemented modifications of Smith predictor is provided. The Section 3 then contains the description of the program itself. Further, the illustrative examples demonstrating the selected capabilities of the software are presented in Section 4. And finally, Section 5 offers some conclusion remarks.

THEORETICAL BACKGROUND

The introductory part has already adumbrated that three modifications of Smith predictor have been studied and implemented into the software support. Due to the limited space, the paper does not focuses on presenting the details of the individual methods and corresponding controller design rules and equations. They can be found in the related literature (Majhi and Atherton 1998; Kaya and Atherton 1999; Hamamci et al. 2001) or in the source code of the program (Matušů and Prokop 2010b). However, the paper is still going to outline the very basic theoretical background of the incorporated methods before the software description itself.

All three techniques have improved the classical Smith predictor loop using more sophisticated and complicated structure with additional controllers. Naturally, all the methods also use mathematical model of really controlled plant including time-delay term in the inner loop. Moreover, this model is assumed during design of controllers as a nominal system. In practice, however, the really controlled can differ from the ideal assumptions.

First, the structure of the modified Smith predictor for unstable and integrating processes, which is shown in

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fig. 1, has been suggested in (Majhi and Atherton 1998). The really controlled plant is formally divided into two blocks representing time-delay-free transfer function $G_r(s)$ and time-delay term $\Theta_r(s)$. Analogically, its mathematical model in the inner loop consists of $G_m(s)$ and $\Theta_m(s)$. Signals w, n, y denote reference value, disturbance in the input of the controlled plant, and output signal, respectively. Such notation is adopted also for the other two modifications. The controller $G_{c1}(s)$ is used to stabilize the unstable pole. The other controllers $G_c(s)$ and $G_{c2}(s)$ then ensure reference tracking and disturbance rejection, respectively, by considering the inner loop as an open-loop stable system. Moreover, the signal outgoing from the controller $G_{c2}(s)$ can be interpreted as an estimation of the disturbance n.

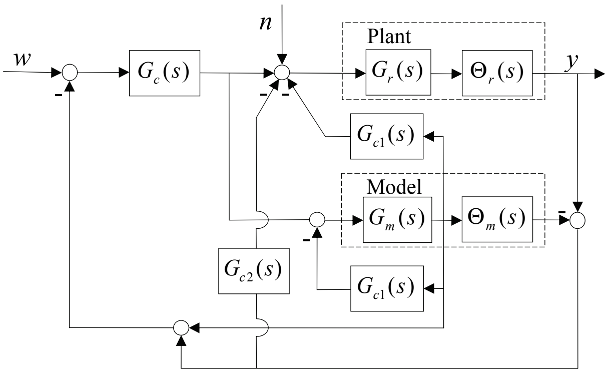


Figure 1: Modified Smith Predictor Structure (Majhi and Atherton 1998)

The second modification of the Smith predictor presented in (Kaya and Atherton 1999) utilizes the structure with trio of controllers depicted in fig. 2, where $G_{c1}(s)$ is a PI controller, $G_{c2}(s)$ is a PD (or only P where it is appropriate) controller and $G_{c3}(s)$ is the disturbance controller introduced in (Mataušek and Micić 1996).

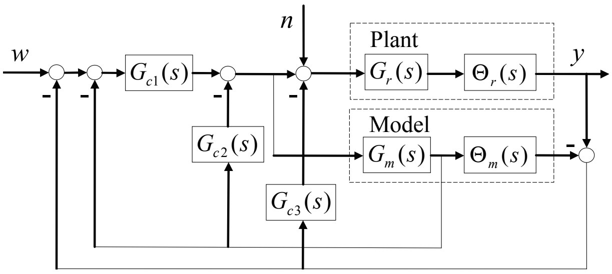


Figure 2: Modified Smith Predictor Structure (Kaya and Atherton 1999)

Finally, the modified Smith predictor design by CDM, proposed in (Hamamci et al. 2001) takes advantage of the structure from fig. 3.

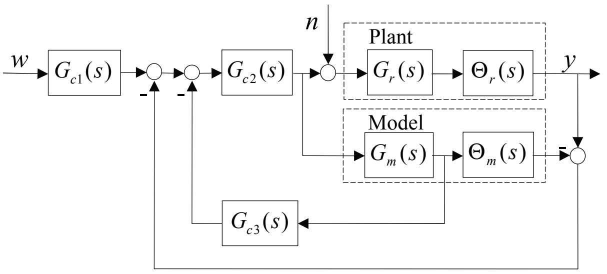
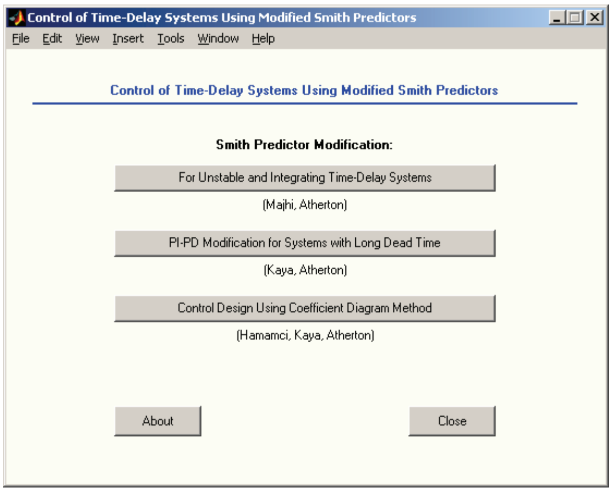


Figure 3: Modified Smith Predictor Structure (Hamamci et al. 2001)

The controller synthesis itself is based on various approaches and techniques according to the applied modification. For example the standard forms for obtaining the optimal closed-loop transfer function parameters in the meaning of integral squared time error (ISTE) criterion; Nyquist stability criterion; a simple algebraic approach to control system design; coefficient diagram; modification of Kessler standard form; or Lipatov stability analysis have been utilized (Mataušek and Micić 1996; Majhi and Atherton 1998; Manabe 1998; Kaya and Atherton 1999; Hamamci et al. 2001; Hamamci and Ucar 2002), etc. The final relations for controller design have been usually pre-derived for first and second order time-delay plants.

PROGRAM DESCRIPTION

The software package with basic instructions can be freely downloaded from the web page (Matušů and Prokop, 2010b). The main window of the program GUI (fig. 4) allows selecting the modification which should be used for a whole control experiment.



Control of Time-Delay Systems Using Modified Smith Predictors

Control of Time-Delay Systems Using Modified Smith Predictors

Smith Predictor Modification:

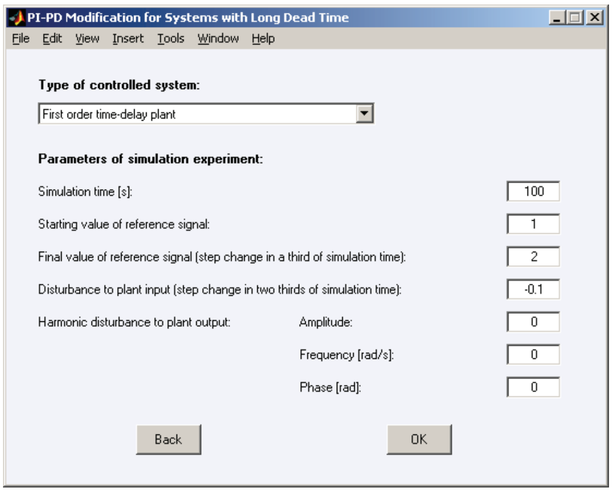
(Majhi, Atherton)

(Kaya, Atherton)

(Hamamci, Kaya, Atherton)

Figure 4: Initial Window of the Program

Subsequently, sort of controlled system (e.g. first order, second order or integrating plant as a special type) can be chosen together with fundamental properties of the experiment (simulation time, reference signal, disturbances) – see fig. 5.



Type of controlled system:
First order time-delay plant

Parameters of simulation experiment:

Simulation time [s]: 100

Starting value of reference signal: 1

Final value of reference signal (step change in a third of simulation time): 2

Disturbance to plant input (step change in two thirds of simulation time): -0.1

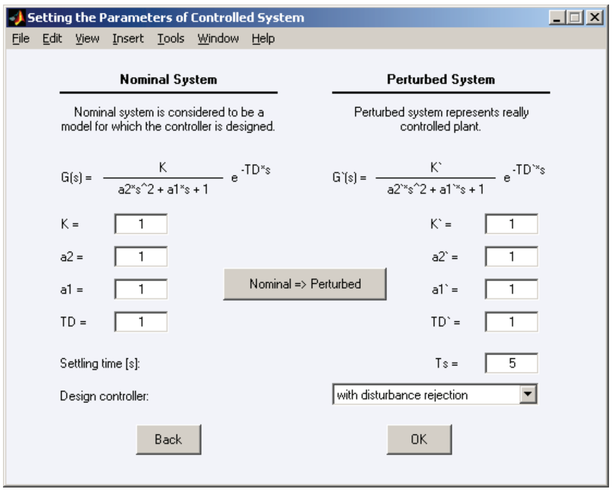
Harmonic disturbance to plant output: Amplitude: 0

Frequency [rad/s]: 0

Phase [rad]: 0

Figure 5: Basic Properties of Control Experiment

In the next step, coefficients of the controlled system of specific type and possibly some other additional parameters depending on the used method can be set as illustrated in fig. 6. However, the program permits not only adjustment of nominal system (considered as a model for control design and in control loops shown in figs. 1-3), but also of the perturbed system (used as a really controlled plant) with potentially different coefficients.



Nominal System

Nominal system is considered to be a model for which the controller is designed.

G(s) = K / (a2*s^2 + a1*s + 1) e^-TD*s

K = 1

a2 = 1

a1 = 1

TD = 1

Settling time [s]:

Design controller:

Perturbed System

Perturbed system represents really controlled plant.

G`(s) = K` / (a2`*s^2 + a1`*s + 1) e^-TD`*s

K` = 1

a2` = 1

a1` = 1

TD` = 1

Ts = 5

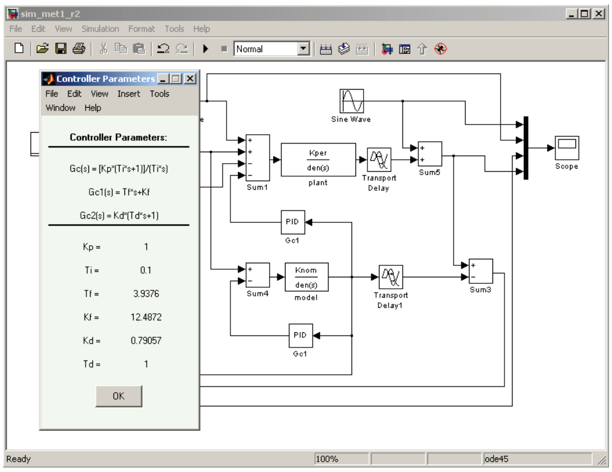
with disturbance rejection

Figure 6: Definition of Parameters for Nominal and Perturbed System

Finally, the program computes the controllers and opens the Simulink scheme where control behaviour with the preset values can be simulated. An example is shown in fig. 7.

ILLUSTRATIVE EXAMPLES

The capabilities of the program are demonstrated on the following two examples. There were assumed the step change of reference signal from 1 to 2 in a third of a simulation time and then the disturbance $n = -0.3$ injected to the input of the controlled plant during the last third of the simulation time for both events.



Controller Parameters:

Gc(s) = [Kp*(Ti*s+1)]/(Ti*s)

Gc1(s) = Tf*s+Kf

Gc2(s) = Kd*(Td*s+1)

Kp = 1

Ti = 0.1

Tf = 3.9376

Kf = 12.4872

Kd = 0.79057

Td = 1

Figure 7: Display of Final Controllers and Simulation Environment

First, a second order time-delay transfer function with complex poles was considered as a controlled plant. The same transfer function was assumed as a nominal system as well:

$$G(s) = \frac{1}{s^2 + 0,2s + 1} e^{-15s} \tag{1}$$

In this case, modified Smith predictor design by CDM was employed. The consideration of the version with disturbance rejection capability leads to the trio of controllers:

$$\begin{aligned} G_{c1}(s) &= 1 \\ G_{c2}(s) &= \frac{1}{0.05579s^2 + 0.3322s} \\ \mathrm{G}_{c3}(s) &= 0.9341s^2 + 1.2929s + 1 \end{aligned} \tag{2}$$

with prescribed settling time:

$$T_s = 3.5\ \text{(sec)} \tag{3}$$

The control result obtained from the program are visualized in fig. 8.

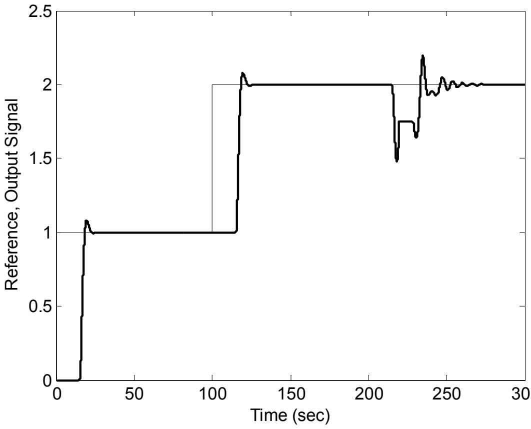


Figure 8: Control Results for the Plant (1)

Further, a second order unstable time-delay transfer function was assumed as a nominal system:

$$G(s)=\frac{2}{(10s-1)(2s+1)}e^{-5s}=\frac{0.1}{s^2+0.4s-0.05}e^{-5s} \tag{4}$$

However, the "really" controlled (perturbed) plant was considered to have 10% higher time delay term than the nominal one:

$$G'(s)=\frac{2}{(10s-1)(2s+1)}e^{-5.5s} \tag{5}$$

Now, modified Smith predictor for unstable and integrating processes was used for calculation of the controllers:

$$\begin{aligned} G_c(s)&=\frac{0.1s+1}{s} \\ G_{c1}(s)&=2.873s+4.7733 \\ G_{c2}(s)&=1.4142s+0.7071 \end{aligned} \tag{6}$$

with presumption (see the program):

$$K_p=T_i=0.1 \tag{7}$$

The fig. 9 shows the output signal of the perturbed plant.

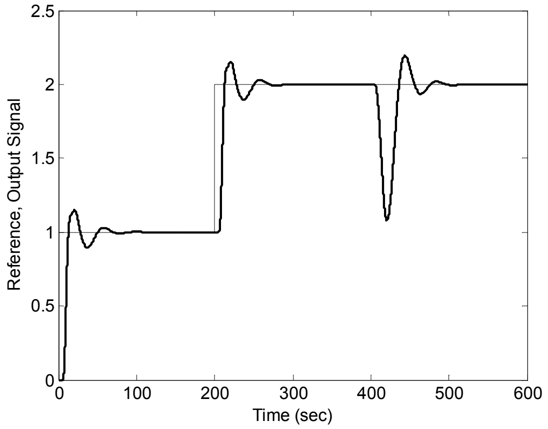


Figure 9: Control Results for the Perturbed Plant (5)

CONCLUSION

The contribution has been focused on presentation of the Matlab program for control of time-delay systems via the modified Smith predictors. The modification for unstable and integrating processes, modified PI-PD Smith predictor for systems with long dead time, and modified Smith predictor design by CDM has been implemented into the software. Several of its capabilities have been briefly illustrated by means of two control and simulation examples including unstable and perturbed systems. The software has been created in Matlab R13 but tested also under several newer versions.

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