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IFAC PapersOnLine 58-26 (2024) 94–99

An interactive software tool to teach ratio control

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Abstract: In this paper we present a software tool, developed using Matlab, that serves as an instructional aid for learning the design of ratio control systems for industrial processes. The tool considers both the series and the parallel control structure and enables the user to tune the parameters of the two PID controllers, as well as subsequently evaluating the impacts of these alterations. The evaluation of the set-point and load disturbance step response, along with the filtering of measurement noise, can be conducted. It is thought that this software has the potential to be effectively utilized in process control courses, facilitating a deeper comprehension of the practical application of theoretical concepts given by the instructor. An illustrative example is given in this context.

Keywords: Control education, interactive tool, ratio control, PID control, tuning.

1. INTRODUCTION

The effectiveness of interactive tools in control education has been widely demonstrated. In fact, they enable users to efficiently assess the outcomes of a design decision and visually analyze what happens when a decision about a control system (for example, changing a parameter) is taken (Dormido, 2004; Guzmán et al., 2013). Consequently, numerous tools have been created in recent years to assist students in comprehending both basic and complex control principles. Various software packages have been employed in the study, such as Matlab/Simulink (Krasnansky and Kozakova, 2012), Modelica (Zakova and Cech, 2018), SIMIT (Ruiz et al., 2015), Easy Java Simulations (Sanchez et al., 2005) and Sysquake (Guzmán et al., 2016, 2011a). Further, these tools can also be integrated into interactive books (Guzmán et al., 2018; Gonzalez et al., 2013) or accessible online, so that there are really many options to exploit them in a learning context. There is a large variety of topics for which interactive tools have been developed, for example, linearization (Guzmán et al., 2012a), Nyquist criterion (Costa-Castelló et al., 2013) system identification (Álvarez et al., 2013, 2011; Guzmán et al., 2009, 2012b, 2014; Rivera et al., 2015), feedforward control (Guzmán et al., 2011b), dead time compensators (Normey-Rico et al., 2009), fractional control (Dormido et al., 2012). Additionally, there has been the development of tools related to particular applications (Sanchez-Zurano et al., 2021; Guzmán et al., 2020).

As they are the most widespread in industry, a particular effort has been devoted to Proportional-Derivative-Integral (PID) so that students can acquire the necessary skills to effectively design these controllers. This entails comprehending the inherent significance of controller parameters, evaluating the trade-off between different control objectives such as set-point following, load disturbance rejection, and noise filtering, as well as acquiring the ability to manually adjust the controller for a specific process and utilizing tuning rules, among other essential aspects. However, it is also important to learn those PID-based control structures that are often used to improve the process control performance without sacrificing the relative ease of use and the basic knowledge about PID controllers. In this context, an interactive tool for cascade control systems has been presented in (Ferrari and Visioli, 2023).

Along the same lines, in this paper we propose an interactive software tool for ratio control (Visioli, 2006). In fact, ratio control is widely used in industry, for example in combustion systems, where it is imperative to regulate the ratio between air and fuel flow to achieve optimal efficiency, or in blending systems where the concentration of the final product and its quality is primarily determined by the ratio between two (or more) process variables.

The tool, created in Matlab so that it can be easily modified and customized if needed, follows the same layout as those already created for PIDA controllers (Ferrari and Visioli, 2022) and cascade control (Ferrari and Visioli, 2023), which aligns with that of (Guzmán et al., 2008). The tool provides the user with the capability to define the process model, adjust the parameters of the PID controllers, and assess the resulting set-point and/or load disturbance step responses. Both the process and control variables are plotted, allowing for the assessment of the impact of measurement noise.

The paper is organized as follows. In Section 2 the fundamentals of ratio control are briefly reviewed. The interactive tool is presented in Section 3. An illustrative example of its use is given in Section 4 and conclusions are in Section 5.

2. RATIO CONTROL

Despite advanced solutions have been recently proposed (Hägglund, 2001; Visioli, 2005a,b; Visioli and Hägglund,

10.1016/j.ifacol.2024.10.277

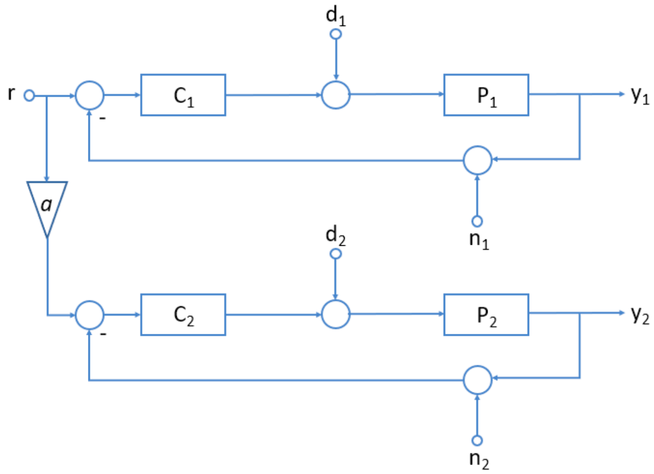


Fig. 1. The parallel ratio control scheme.

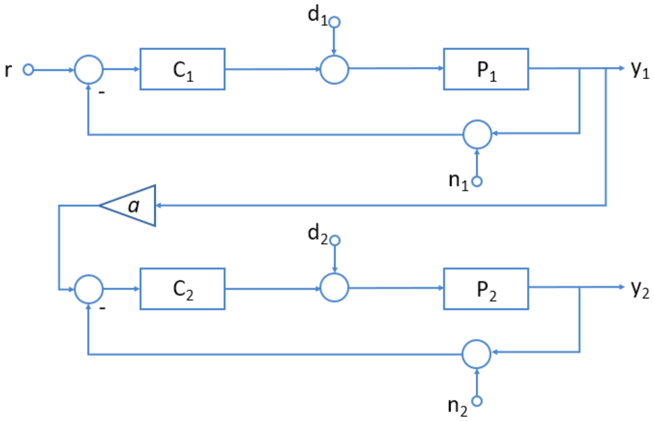


Fig. 2. The series ratio control scheme.

2019), the conventional approaches for ratio control systems consider the utilization of either parallel or series architectures. In the parallel scheme (see Figure 1) the same set-point signals, although appropriately scaled by the ratio constant, is given to the two closed-loop systems that regulate the two process variables. In this scenario, if the two feedback control systems exhibit identical dynamics, the desired ratio is maintained throughout the set-point transient response. However, this is not the case if the two loops possess distinct dynamics, such as the presence of varying dead times in the two processes, or if load disturbances arise or the control variables reach a state of saturation. In contrast, in the series scheme (see Figure 2), the process variable of the master (first) loop is used, after multiplying it by the ratio constant, as the reference value for the slave (second) closed-loop system. In this scenario, the ratio can be kept in the event of a load disturbance on the first process. However, the performance may be suboptimal when there is a change in the set-point, as the process variable of the slave loop consistently lags behind that of the master loop. Therefore, both of these options have their own pros and cons. In any case, the two PID controllers should be tuned by taking into account the employed schemes and the dynamics of the two processes, rather than considering only the single closed-loop systems.

3. INTERACTIVE TOOL

Figure 3 shows the educational tool as it appears when it is opened. The tool is mainly composed of two different parts; in the left hand side the user can select the processes to control, the type of architecture that is employed, the value of the ratio between the two process variables, and the parameters of the two PID controllers. In the right hand side there is the graphical visualization of the responses of the two systems. Both the process and the control variables are plotted and responses to set-point changes, load disturbance steps and measurement noise can be evaluated.

3.1 Selection of the processes

The models of the two processes can be inserted by clicking on the specific tab in the left hand side of the screen. Then, as it is shown in Figure 4, the two transfer functions of the processes can be entered by specifying them as ratios of polynomials (‘num/den form’) or by giving their poles, zeros and gains (‘zpk form’).

3.2 Selection of the control architecture

In the upper part of the tab ‘Controller Configuration’, the user can select the parameter a, which is the desired ratio between the two process variables y_1 and y_2. It is then necessary to select which type of control scheme will be implemented: series or parallel.

3.3 Setting the parameters of the controllers

By clicking on one of the two tabs ’C_1’ and ’C_2’ the parameters of the two controllers can be adjusted. They are PID controllers defined as

$$C_i(s) = K_p \left(1 + \frac{1}{T_i s} + \frac{T_d s}{\frac{T_d}{N} s + 1}\right) \quad i = 1, 2$$

where K_p is the proportional gain, T_i and T_d are, respectively, the integral and derivative time constants, and N is the derivative filter parameter. Actually, it is possible to select if the controller is proportional (P), proportional-integral (PI) or proportional-integral-derivative (PID). For each controller, it is possible to set each one of the controller parameters. This can be done through sliders or by directing inserting a value in the specific box. In any case the corresponding slider value is updated, and the limits of the slider are adjusted to half and double of the current value. The tick boxes ‘Disable Integral Action’ and ’Disable Derivative Action’ can also be used for disabling the corresponding actions. If this is done, the values $T_i = \infty$ and $T_d = 0$ are used in the control algorithm, respectively. If the tick box ‘Avoid Derivative Kick’ is selected, the derivative part of the controller does not take as input the control error but the negative process variable. In that way, the derivative kick due to a set-point step is avoided.

3.4 Evaluation of the control system

The tool allows the user to block on the screen the current plots to evaluate how the variation of the controller parameters, the changing of architecture, or the modification of the disturbances or noises affect the response of the systems. To evaluate the overall performance, a specific index is calculated as the integral of the absolute value of the difference between the two process outputs, scaled with the ratio parameter a:

$$\int_{0}^{t_{end}} |ay_1(t) - y_2(t)| dt \tag{1}$$

3.5 Visualization

In the right hand side of the screen, there is the visualization panel. There are two different plots: in the top one there are the process variables of the two systems, while in the bottom one there are the two manipulated variables. In both plots there is a legend, that helps the user to distinguish the signals, which is really important, especially when the tick box 'Block Graph' is selected. In fact, this function allows the user to keep a response on the screen and to plot a new one (obtained by changing the parameters of the controllers) so that a comparison can be performed and the effect of changing one or more parameters can be clearly evaluated.

Below the two plots, the user can select the time instants when load disturbances occur on the processes as well as their amplitude. Further, it is possible to insert measurement noise in both feedback lines and, also in this case, the time instants when the noise signals start to be applied and the amplitude of the noise can be selected by appropriate functions. In this way, by considering the of the different disturbances and noises in different time intervals, the user can clearly evaluate the effects of the modifications in the controllers.

Finally, in the right-top part of the screen, there is an icon representing a subtraction node and a block. The user, by clicking on that, can see the block scheme of the control architecture that is currently simulated by the tool, that is, if the two controllers are in series or in parallel configuration and if the 'Avoid Derivative Kick' tick is selected (see Figure 5, where the derivative action is applied to the process variable for C_1 and not for C_2).

4. ILLUSTRATIVE EXAMPLE

An illustrative example of the usage of the interactive tool is given in this section. The two processes that are considered are (Visioli and Hägglund, 2019):

$$P_1(s) = \frac{1}{(s+1)^8} \tag{2}$$

and

$$P_2(s) = \frac{1}{s+1}e^{-0.2s} \tag{3}$$

Note that the dynamics of $P_2(s)$ is faster than that of $P_1(s)$, which suggests that, in principle, it is better to use a series configuration. Anyway, for educational purposes, both cases, series and parallel, are tested. The ratio parameter a is set to 1 for the sake of simplicity. After having inserted the two processes, at the beginning the first controller is tuned. This can be done with a trial-and-error procedure by considering only the set-point step response of the closed-loop system, so that the physical meaning of the PID parameters can be well understood. A screenshot of the final result is shown in Figure 6. The parallel configuration is initially considered. The controller C_2 is tuned also in this case by a trial-and-error procedure, by taking into account the set-point following task, with the aim of achieving the best possible performance. The result is illustrated in Figure 7, where it appears that, being the two systems dynamics completely different, it is very difficult to obtain very similar transients for the two process variables. In Figures 8 and 9, it is possible to observe the performance achieved with this configuration in case of load disturbances and noise acting on the two systems outputs. Indeed, the user can see how the two loops are independent, so when a disturbance occurs in the first process, there is no effect in the second loop. It can be also clearly seen that there is a bigger noise amplification in the first controller, because in the second controller the derivative action is disabled (actually, a PI has been employed).

Then, the series scheme is employed, keeping the same tuning for the controller C_1 and retuning the controller C_2 as shown in Figure 10. It appears that, being the second process much faster than the first one, the second process variable can track the first one, yielding a better result than the parallel case. Figure 11 shows how the overall control system compensates for disturbances occurring in the two loops. Since the process variable of the first loop is used as the set-point signal of the second loop, the load disturbance in the first loop affects the second one and allows the ratio to be kept at a certain level. The second loop is tuned in a more aggressive way, so that the disturbance in the second loop is rejected in a short time interval.

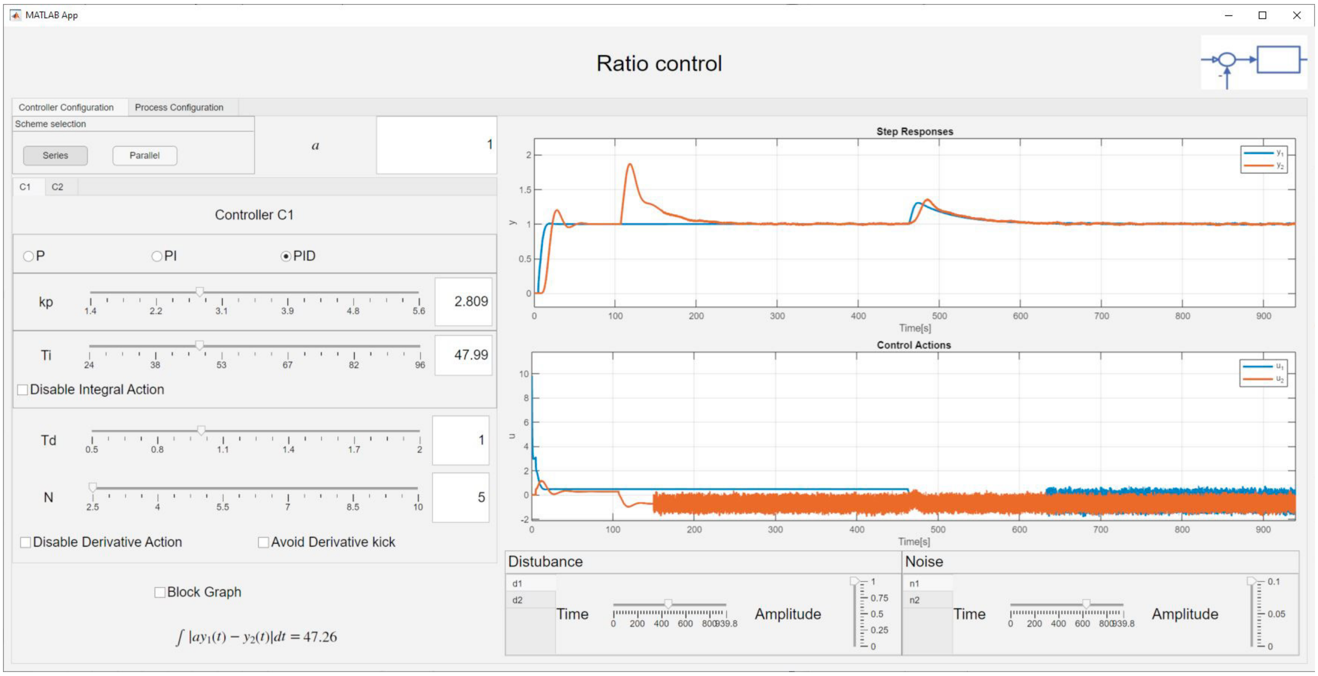
Also in this case, the effect of the noise is evaluated, see Figure 12. The noise in the first loop affects both responses and both control actions, while the noise in the second loop affects only its control variable. It appears that, despite the derivative action is again disabled, the aggressive tuning of the second controller yields, in any case, an amplification of the measurement noise that can be potentially detrimental for the actuator.

5. CONCLUSIONS

In this paper we have presented an interactive software tool to learn the fundamentals of ratio control. It is believed that it can be fruitfully employed in those courses where process control PID-based control architectures are taught. In particular, the tool can be employed to learn the different issues that emerge in the design of a ratio control system, that is, the choice of the control architecture and the tuning of the controllers. The set-point following, load disturbance rejection and noise filtering tasks can be evaluated and, therefore, the user can acquire a complete knowledge about the effects of different selections of the parameters. The interactive tool can be downloaded from https://industrial-control.unibs.it/resources

ACKNOWLEDGEMENTS

This research was partially funded by the Italian Government fund PON DM1061 of "Ministero dell'Università e della Ricerca"


MATLAB App

Ratio control

Controller Configuration | Process Configuration

Scheme selection: Series | Parallel

a = 1

C1 | C2

Controller C1

○ P ○ PI ● PID

kp = 2.809

Ti = 47.99

☐ Disable Integral Action

Td = 1

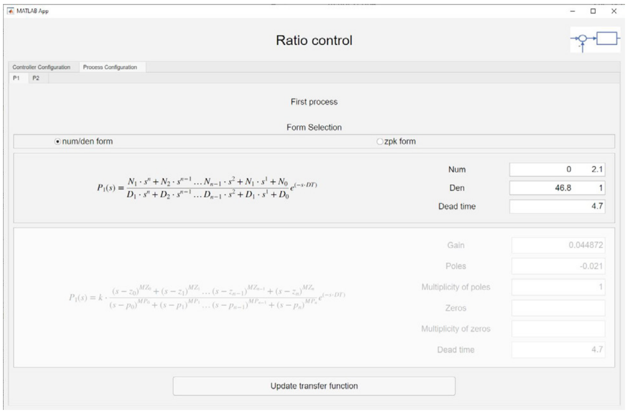
N = 5

☐ Disable Derivative Action ☐ Avoid Derivative kick

☐ Block Graph

$\int |ay_1(t) - y_2(t)|dt = 47.26$

Fig. 3. Screenshot of the main page of the educational tool


MATLAB App

Ratio control

Controller Configuration | Process Configuration

P1 | P2

First process

Form Selection

● num/den form ○ zpk form

$$P_1(s) = \frac{N_1 \cdot s^n + N_2 \cdot s^{n-1} \dots N_{n-1} \cdot s^2 + N_1 \cdot s^1 + N_0}{D_1 \cdot s^n + D_2 \cdot s^{n-1} \dots D_{n-1} \cdot s^2 + D_1 \cdot s^1 + D_0} e^{(-s \cdot DT)}$$

Num: 0 2.1

Den: 46.8 1

Dead time: 4.7

$$P_1(s) = k \cdot \frac{(s-z_0)^{MZ_0} + (s-z_1)^{MZ_1} \dots (s-z_{n-1})^{MZ_{n-1}} + (s-z_n)^{MZ_n}}{(s-p_0)^{MP_0} + (s-p_1)^{MP_1} \dots (s-p_{n-1})^{MP_{n-1}} + (s-p_n)^{MP_n}} e^{(-s \cdot DT)}$$

Gain: 0.044872

Poles: -0.021

Multiplicity of poles: 1

Zeros:

Multiplicity of zeros:

Dead time: 4.7

Update transfer function

Fig. 4. Screenshot of the page where the transfer function of the processes are inserted.

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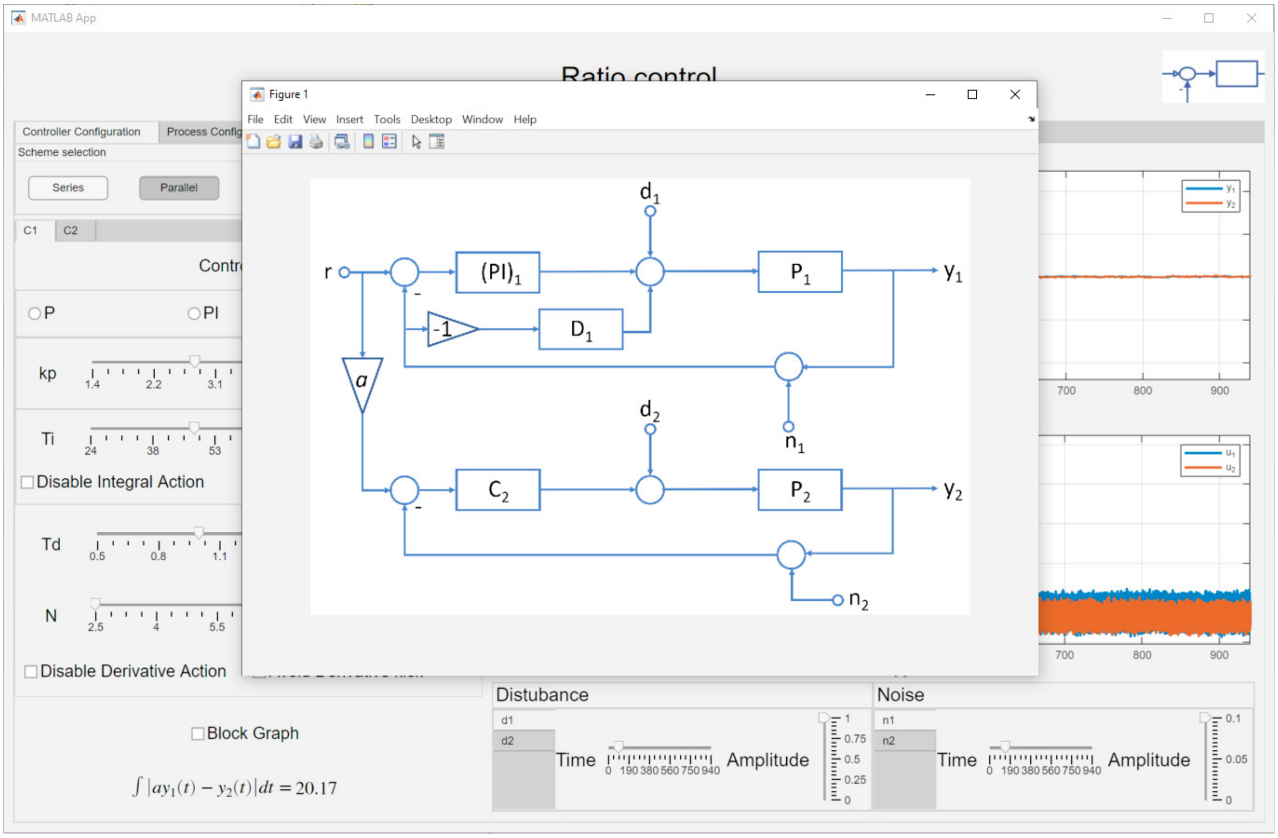

$\int |ay_1(t) - y_2(t)|dt = 20.17$

Fig. 5. Screenshot when the user clicks on the top right icon.

190–195.

Guzmán, J., Rivera, D., Berenguel, M., and Dormido, S. (2014). ITCLI: An interactive tool for closed-loop identification. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, volume 19, 12249–12254.

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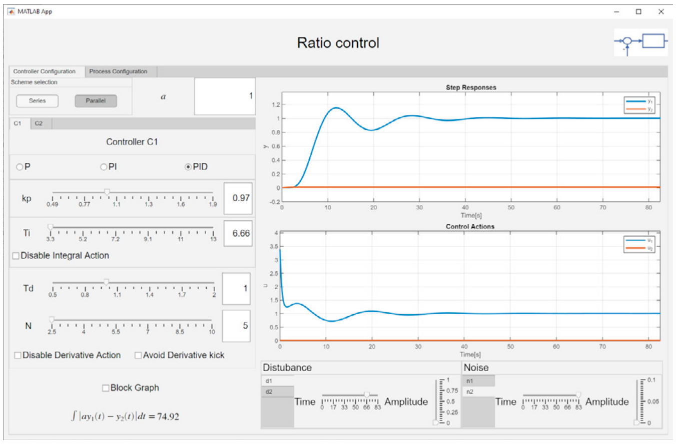


a 1

kp 0.97

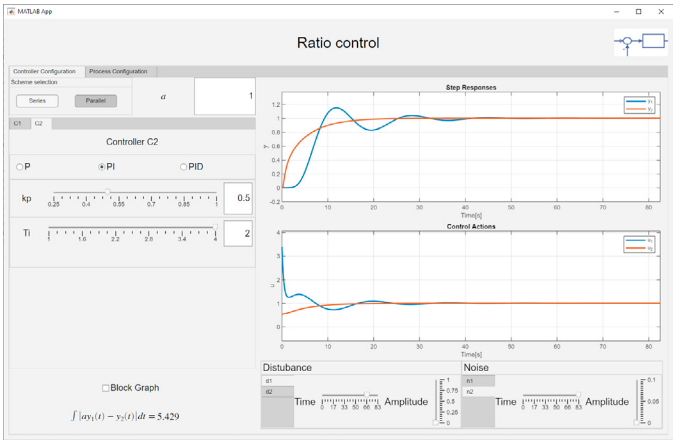
Ti 6.66

Td 1

N 5

$\int |ay_1(t) - y_2(t)|dt = 74.92$

Fig. 6. Tuning of C_1



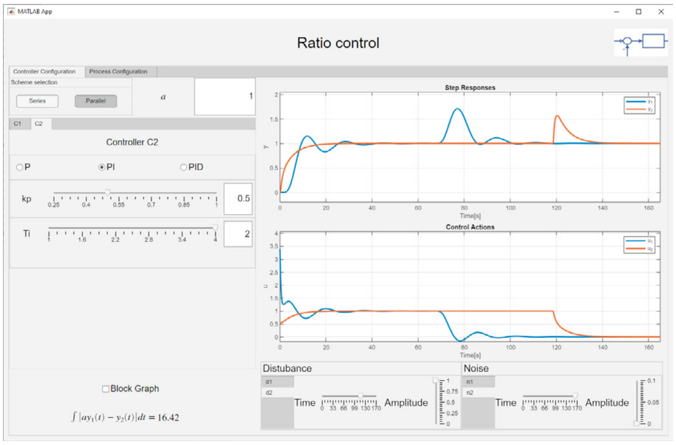
a 1

kp 0.5

Ti 2

$\int |ay_1(t) - y_2(t)|dt = 5.429$

Fig. 7. Tuning of C_2 in parallel configuration



Ratio control

Scheme selection: Parallel

a 1

Controller C2

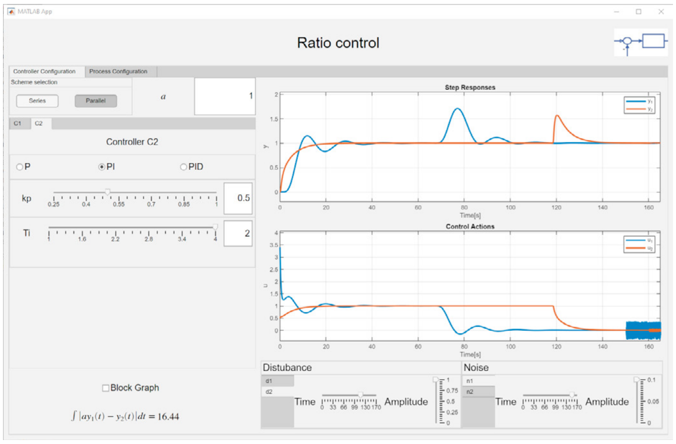
○P ●PI ○PID

kp 0.5

Ti 2

$\int |ay_1(t) - y_2(t)|dt = 16.42$

Fig. 8. Disturbance responses in parallel configuration



Ratio control

Scheme selection: Parallel

a 1

Controller C2

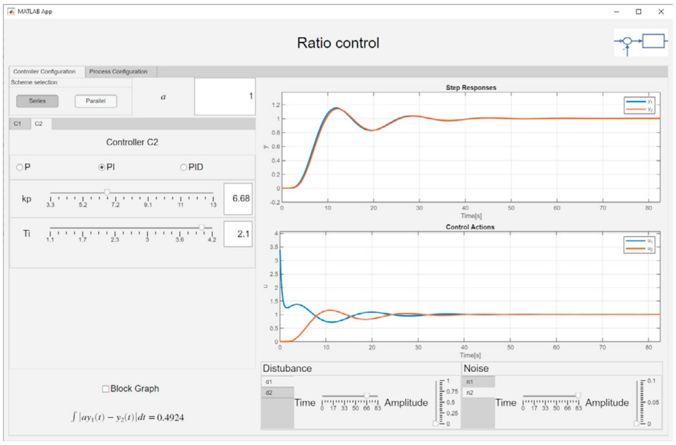
○P ●PI ○PID

kp 0.5

Ti 2

$\int |ay_1(t) - y_2(t)|dt = 16.44$

Fig. 9. Noise responses in parallel configuration



Ratio control

Scheme selection: Series

a 1

Controller C2

○P ●PI ○PID

kp 6.68

Ti 2.1

$\int |ay_1(t) - y_2(t)|dt = 0.4924$

Fig. 10. Tuning of C_2 in series configuration

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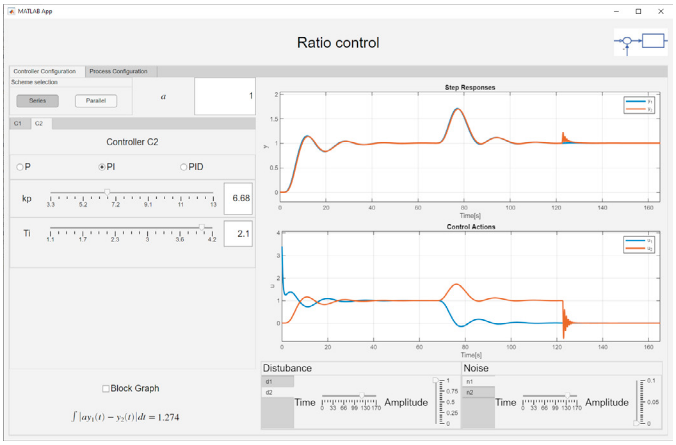


Ratio control

Scheme selection: Series

a 1

Controller C2

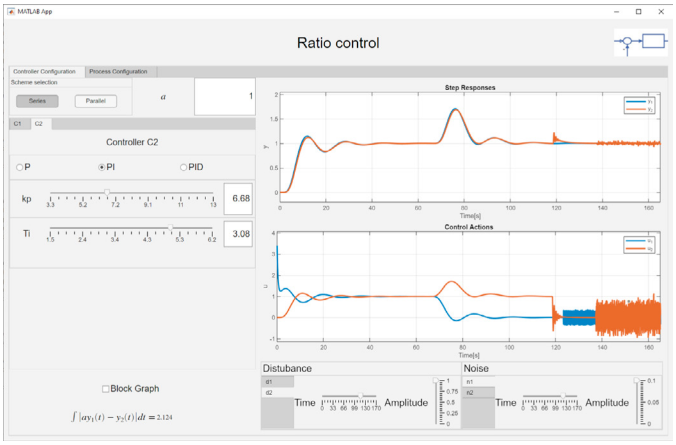
○P ●PI ○PID

kp 6.68

Ti 2.1

$\int |ay_1(t) - y_2(t)|dt = 1.274$

Fig. 11. Disturbance responses in series configuration



Ratio control

Scheme selection: Series

a 1

Controller C2

○P ●PI ○PID

kp 6.68

Ti 3.08

$\int |ay_1(t) - y_2(t)|dt = 2.124$

Fig. 12. Noise responses in series configuration

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