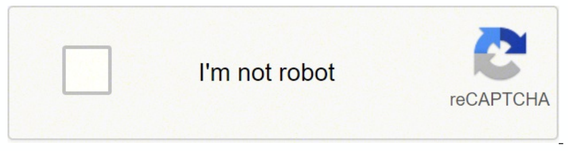

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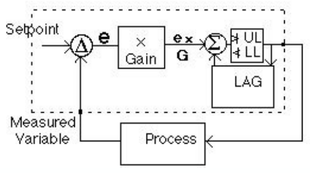

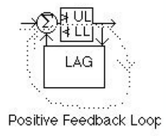

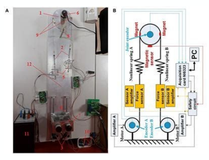

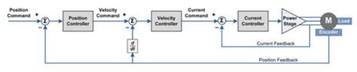

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This example shows how to jointly tune the inner and outer loops of a cascade architecture with the systune command. The outer loop must have a bandwidth of at least 0.2 rad/s and the inner loop bandwidth should be ten times larger for adequate disturbance rejection.Tuning the PID Controllers with SYSTUNEWhen the control system is modeled in Simulink, use the slTuner interface in Simulink Control Design™ to set up the tuning task. Cascade control is often used to achieve smooth tracking with fast disturbance rejection. To further validate the design, plot the tuned responses to a step command r and step disturbance d2:% Response to a step command H = getIOTransfer(ST,'r','y1'); clf, step(H,30), title('Step command') % Response to a step disturbance H = getIOTransfer(ST,'d2','y1'); step(H,30), title('Step disturbance') Once you are satisfied with the linear analysis results, use writeBlockValue to write the tuned PID gains back to the Simulink blocks. A robustness measure is defined, and it is shown that it can reflect the interaction between the inner loop and the outer loop and has a clear indication of the robustness of each loop. Built with Sphinx using a theme provided by Read the Docs. The inner loop is typically faster than the outer loop to reject disturbances before they propagate to the outer loop. The measure can serve as a graphic aid for tuning the cascade controller. In this example, the inner loop bandwidth is selected as 2 rad/s, which is ten times higher than the desired outer loop bandwidth. ---------- Block 2: rct_cascade/C2 = 1 Kp + Ki * --- s with Kp = 0.722, Ki = 1.23 Name: C2 Continuous-time PI controller in parallel form. The possibility to operate different controllers in a specific sequence is given by the variables net.controller.order and net.controller.level, which we will go into later. Use as the target loop shape for the outer loop to enforce integral action with a gain crossover frequency at 0.2 rad/s:% Outer loop bandwidth = 0.2 s = tf('s'); Req1 = TuningGoal.LoopShape('y1',0.2/s); % loop transfer measured at y1 Req1.Name = 'Outer Loop'; Use for the inner loop to make it ten times faster (higher bandwidth) than the outer loop. Controller C1 in the outer loop is the primary controller that regulates the primary controlled variable y1 by setting the set-point of the inner loop. See Alsopidstune | pidstd Related Topics Elements of a network which contain a control loop can be modelled as so called Controller. Next use "LoopShape" requirements to specify the desired bandwidths for the inner and outer loops. Controller Order Level Controller A 1 1,2 Controller B 2 2 © Copyright 2016-2020 by Fraunhofer IEE and University of Kassel Revision 8c73173a. To constrain the inner loop transfer, make sure to open the outer loop by specifying y1 as a loop opening:% Inner loop bandwidth = 2 Req2 = TuningGoal.LoopShape('y2',2/s); % loop transfer measured at y2 Req2.Openings = 'y1'; % with outer loop opened at y1 Req2.Name = 'Inner Loop'; You can now tune the PID gains in C1 and C2 with systune:ST = systune(ST0,[Req1,Req2]); Final: Soft = 0.86, Hard = -Inf, Iterations = 60 Use showTunable to see the tuned PID gains. For a cascade control system to function properly, the inner loop must respond much faster than the outer loop.In this example, you will design a single loop control system with a PI controller and a cascade control system with two PI controllers. This example shows how to design a cascade control loop with two PI controllers using the pidtune command.Cascade control is mainly used to achieve fast rejection of disturbance before it propagates to the other parts of the plant. ---------- Block 2: rct_cascade/C2 = 1 Kp + Ki * --- s with Kp = 0.1, Ki = 0.1 Name: C2 Continuous-time PI controller in parallel form. List the tunable blocks, mark the signals r and d2 as inputs of interest, and mark the signals y1 and y2 as locations where to measure open-loop transfers and specify loop shapes.ST0 = slTuner('rct_cascade',{'C1','C2'}); addPoint(ST0,{'r','d2','y1','y2'}) You can query the current values of C1 and C2 in the Simulink model using showTunable. Note the -1 sign to compute the negative-feedback open-loop transfer:L1 = getLoopTransfer(T,'y1',-1); % crossover should be at .2 L2 = getLoopTransfer(T,'y2',-1,'y1'); % crossover should be at 2 bodemag(L2,L1,{1e-2,1e2}), grid legend('Inner Loop','Outer Loop') See AlsoslTuner | systune (slTuner) Related TopicsPID Tuning for Setpoint Tracking vs. Validating the DesignThe final value is less than 1 which means that systune successfully met both loop shape requirements. They implement a controlling mechanism as well as a convergence check and are being registered at the used network net.controller. ABSTRACT The robustness and performance of the cascade control system are analyzed in this article. Figure 1: Cascade ArchitectureFirst create parametric models of the tunable PI and PID controllers.C1 = tunablePID('C1','pid'); C2 = tunablePID('C2','pi'); Then use "analysis point" blocks to mark the loop opening locations y1 and y2.LS1 = AnalysisPoint('y1'); LS2 = AnalysisPoint('y2'); Finally, create a closed-loop model T0 of the overall control system by closing each feedback loop. The result is a generalized state-space model depending on the tunable elements C1 and C2.InnerCL = feedback(LS2*G2*C2,1); T0 = feedback(G1*InnerCL*C1,LS1); T0.InputName = 'r'; T0.OutputName = 'y1'; You can now tune the PID gains in C1 and C2 with systune.T = systune(T0,[Req1,Req2]); Final: Soft = 0.86, Hard = -Inf, Iterations = 133 As before, use getIOTransfer to compute and plot the tuned responses to a step command r and step disturbance entering at the location y2:% Response to a step command H = getIOTransfer(T,'r','y1'); clf, step(H,30), title('Step command') % Response to a step disturbance H = getIOTransfer(T,'y2','y1'); step(H,30), title('Step disturbance') You can also plot the open-loop gains for the inner and outer loops to validate the bandwidth requirements. Block 1: rct_cascade/C1 = 1 s Kp + Ki * --- + Kd * -------- s Tf*s+1 with Kp = 0.0519, Ki = 0.0187, Kd = 0.0477, Tf = 0.015 Name: C1 Continuous-time PIDF controller in parallel form. This operation is called a cascade control. The following picture describes the dependence of both methods. In order to have an effective cascade control system, it is essential that the inner loop responds much faster than the outer loop.Tune inner-loop controller C2 with open-loop bandwidth at 2 rad/s.C2 = pidtune(P2,pidstd(1,1),2); C2C2 = 1 1 Kp * (1 + ---- * ---) Ti s with Kp = 0.244, Ti = 0.134 Continuous-time PI controller in standard form Tune outer-loop controller C1 with the same bandwidth as the single loop system.% Inner loop system when the control loop is closed first clsys = feedback(P2*C2,1); % Plant seen by the outer loop controller C1 is clsys*P1 C1 = pidtune(clsys*P1,pidstd(1,1),0.2); C1C1 = 1 1 Kp * (1 + ---- * ---) Ti s with Kp = 0.015, Ti = 0.716 Continuous-time PI controller in standard form Performance ComparisonFirst, plot the step reference tracking responses for both control systems.% single loop system for reference tracking sys1 = feedback(P*C,1); sys1.Name = 'Single Loop'; % cascade system for reference tracking sys2 = feedback(clsys*P1*C1,1); sys2.Name = 'Cascade'; % plot step response figure; step(sys1,'r',sys2,'b') legend('show','location','southeast') title('Reference Tracking')Secondly, plot the step disturbance rejection responses of d2 for both control systems.% single loop system for rejecting d2 sysd1 = feedback(P1,P2*C); sysd1.Name = 'Single Loop'; % cascade system for rejecting d2 sysd2 = P1/(1+P2*C2+P2*P1*C1*C2); sysd2.Name = 'Cascade'; % plot step response figure; step(sysd1,'r',sysd2,'b') legend('show') title('Disturbance Rejection')From the two response plots you can conclude that the cascade control system performs much better in rejecting disturbance d2 while the set-point tracking performances are almost identical. Disturbance Rejection Moreover, it is observed that the cascade controller can be tuned individually for each loop instead of sequentially. When a simulation is being invoked through runpp(net, run_control=True), the run_control() method iteratively calls the controlling-method control_step() on each initialized controller until all of them are converged. This control_step() can be calculated for a single point in time as well as a simulation of discrete consecutive points in time using the timeseries module method run_timeseries(). See also time series module Each Controller has the variables order and level with the default value 0. The simplest cascade control system involves two control loops (inner and outer) as shown in the block diagram below. Both variables enable the possibility to operate different controllers in a specific sequence. (Simulink® is not supported in MATLAB® Online.)open_system('rct_cascade') Plant Models and Bandwidth RequirementsIn this example, the inner loop plant G2 isand the outer loop plant G1 isG2 = zpk([],-2,3); G1 = zpk([],[-1 -1 -1],10); We use a PI controller in the inner loop and a PID controller in the outer loop. The simplest cascade architecture involves two control loops (inner and outer) as shown in the block diagram below. Following flow chart explains the general usage. The responses of the two control systems are compared for both reference tracking and disturbance rejection.PlantIn this example, the inner loop plant P2 is The outer loop plant P1 is P2 = zpk([],-2,3); P1 = zpk([],[-1 -1 -1],10);Designing a Single Loop Control System with a PI ControllerUse pidtune command to design a PI controller in standard form for the whole plant model P = P1 * P2.The desired open loop bandwidth is 0.2 rad/s, which roughly corresponds to the response time of 10 seconds.% The plant model is P = P1*P2 P = P1*P2; % Use a PID or PIDSTD object to define the desired controller structure C = pidstd(1,1); % Tune PI controller for target bandwidth is 0.2 rad/s C = pidtune(P,C,0.2); CC = 1 1 Kp * (1 + ---- * ---) Ti s with Kp = 0.0119, Ti = 0.849 Continuous-time PI controller in standard form Designing a Cascade Control System with Two PI ControllersThe best practice is to design the inner loop controller C2 first and then design the outer loop controller C1 with the inner loop closed. You can then conduct a more thorough validation in Simulink.Equivalent Workflow in MATLABIf you do not have a Simulink model of the control system, you can perform the same steps using LTI models of the plant and Control Design blocks to model the tunable elements. Confirm this by inspecting the tuned control system ST with viewGoalNote that the inner and outer loops have the desired gain crossover frequencies. Controller C2 in the inner loop is the secondary controller that rejects disturbance d2 locally before it propagates to P1. The control system is unstable for these initial values as confirmed by simulating the Simulink model. Block 1: rct_cascade/C1 = 1 Kp + Ki * --- s with Kp = 0.1, Ki = 0.1 Name: C1 Continuous-time PI controller in parallel form.

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