Experiment Procedure
Robot Modelling, Identification, and Control

IJC - Independent Joint Control

May 8, 2025

⚠ **IMPORTANT:** It is essential that you carry out the following steps before starting the experiment!

1.) Select "`Fixed-Step`" as the solver for your Simulink model with a variable Sample Time $T_s = 0.001$. You will select this later depending on the task. You can set this under "`Model Configuration Parameters`" in the upper bar.

2.) Avoid hardcoded values, i.e. only use variables within Simulink and define them outside in a central script which is called by the simulation via callback[1].

3.) Deactivate the check mark at "`Limit data points to...`" in Scopes in order not to lose any data points during longer simulation times.

4.) If you need to compare two systems, the easiest way is to copy the original system and make the changes to the copy. So you always have both versions available.

5.) For "`To Workspace`" blocks, select "`Array`" as the storage format, since they are the easiest to handle.

6.) If the function of a command is not clear, use MATLAB Help.

7.) Use the "`clear`" command in your main script to clean up your workspace before performing a task and avoid errors due to old data.

8.) If you need to integrate a variable twice, use **Integrator, Second-Order** block, instead of using two integrator blocks in series (look at Fig. 1)

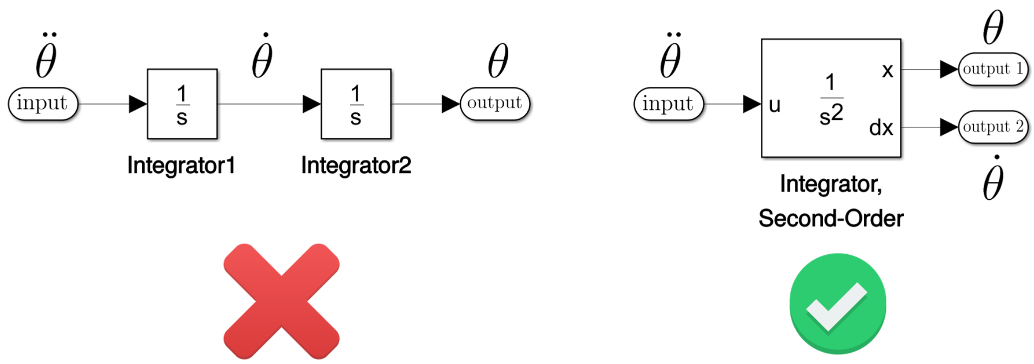

Figure 1: Second-order integration in Simulink

1 Experiment procedure

⚠ **IMPORTANT:** In Moodle you are provided with a MATLAB Live Editor file which will guide you through the intermediate steps needed to complete the tasks. Fill in the lines where you see the legend: `<YOUR CODE HERE>`. **Items marked with a ★ must be included in your experiment report**.

T1 (**1 P**) Model the motor in the block diagram in Fig. 2 using Simulink gain and **Integrator, Second-Order** block. The model has two inputs namely disturbance d, armature voltage V_a and two outputs namely, motor position θ and velocity $\dot{\theta}$ (look at Fig. 3). The motor parameters are listed in Table 1.

Hint: In order to test your model apply 1 volt to the armature with no disturbance, you should see that the motor velocity converges to $2\ \frac{rad}{s}$ after 70 seconds, in a damped curve.

★ Plot the motor velocity $\dot{\theta}(t)$ against time (100 seconds) in your report.

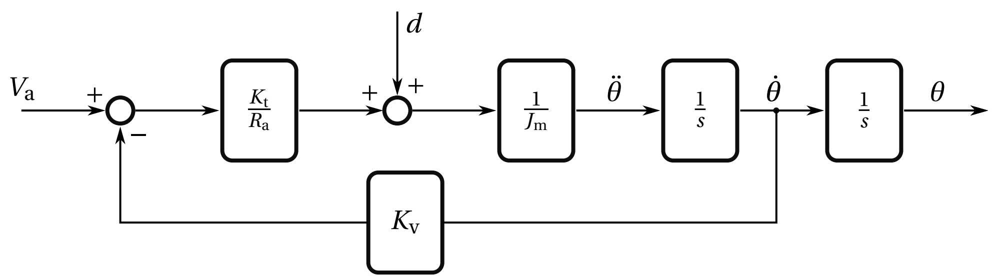

Figure 2: Block diagram of DC motor

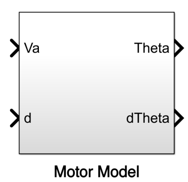

Figure 3: Input-output motor model (masked system)

T2 (**5 P**) Now add the amplifier (which is the gain G_v) and create the control voltage signal V_c.

- Close the loop simply with joint position measurement. The control set point (desired position) is 1 rad with no disturbance. **Use an amplifier gain of** $G_\mathrm{v} = 1$.
  ★ Plot the motor position on top of the set-point against time (100 seconds) in your report.
- Now add a disturbance with magnitude 1 Nm.
  ★ In your report add the corresponding plot. Was the setpoint reached? Elaborate on your observations.

- Derive the closed-loop transfer functions $\frac{\Theta(s)}{\Theta_r(s)}$ and $\frac{\Theta(s)}{D(s)}$.
  ★ Include the corresponding expressions in your report
  ★ How can you explain your observations relative to the disturbance and the effect of the gain G_v according to the transfer functions?
  ★ Is there a way to reduce the impact of the disturbance with the available setup? (you should not add any new elements)
  ★ What happens to the signal $\theta(t)$ when you fix the problem with the current setup? Elaborate on your answer based on the poles of the closed loop system.
  Hint: Optional: You can use root locus approach to answer this question. You have to be careful as MATLAB `rlocus` puts the gain in the feedback loop. But the gain of this system (G_v) is in the forward loop.

T3 (**4 P**) In order to improve the system performance we intend to use PI controller in this task.

- Set the amplifier gain G_v to 1.
- Knowing that Matlab `rlocus` syntax assumes controller parameter in feedback path, rewrite the closed-loop transfer function with PI controller in the forward path and feedback gain K.
- Now analyze the closed-loop transfer function in steady-state.
  ★ How do you describe the relation between feedback gain K and steady-state error? How could you compensate for this?
- According to your findings, design a stabilizing PI controller in the forward path with root locus method.
  Hint: Please remember that `rlocus` plots the root locus as a function of the feedback gain. Now as you know what feedback gain you are allowed to use, try to stabilize the system at that specific feedback gain K.
  ⚠ **IMPORTANT:** In this task you do not design feedback gain K, but the PI controller gains. You are only allowed to use one value for K. Therefore, change the values of your controller gain and plot the root locus. See if your system is stable for the allowed value of K.
  ★ Plot the root locus of the closed loop system with your designed PI controller. On the plot, show where the poles of the closed-loop system are located for the allowed value of the feedback gain K. Then, explain if your system is stable or not.
- Once you are satisfied with the design, add a disturbance value of 1 Nm to the corresponding port of your system. Does your controller reject the disturbance?
  Hint: Since you are using a PI controller, the system response can be slow.
  ★ Show the closed-loop system with your designed PI controller block diagram in your report (you can take a screenshot of your Simulink model, but make sure it is clear.).
  ★ Plot the step response of the closed-loop system on the top of the reference signal, with and without 1 N.m disturbance.

T4 (**3 P**) In this task, we intend to have a more realistic situation by assuming that the motors are used for a 2-link robot arm.

- Make a copy of your previous system. Now remove the PI controller and keep the amplifier.
- Make another copy of the motor with amplifier. Each motor will actuate one link.
- Now use the gravity function –i.e. $g(q)$– from the previous experiment. As we are dealing with rigid-body robot manipulators, the motor position θ is the same as link position q.
  Hint: You are given the links parameters in the provided template.
  ★ How can the gravity function be incorporated into the model? Provide the answer in your report.
- Now close the loop with proper feedback path(s?). The setpoint is 1 rad for both motors.
- Use Simulink PID controller block and tune the controller with tuner GUI. The settling time has to be shorter than 10 seconds and overshoot less than 20%.
  Hint: As mentioned in the script you can have only PI controller in the forward path. The D

controller is in the feedback path from motor velocity measurement.
Hint: Try to give some values for the velocity feedback gain and then tune the PI controller in the forward path with the tuner GUI.
★ **Include in your report a screenshot of the closed-loop system such that the block diagram of your controller(s), including your incorporated gravity function, is clearly visible.**
★ **Plot the step response (for both motors, simultaneously) of the closed-loop system on the top of the reference signal, when the links are attached to the motors**.
★ **Explain how the D element in your controller improved your results**.

Table 1: DC motor parameters

Variable name	Physical meaning	Value	Unit
θ	Rotor position	System output	rad
V_{c}	Control voltage	Control variable	V
V_{a}	Armature voltage	System input	V
G_{v}	Amplifier gain	1	
R_{a}	Armature resistance	0.3	Ω
K_{v}	Motor constant	0.5	V.s/rad
K_{t}	Torque constant	0.5	Nm/A
J_{m}	Motor moment of inertia	6	Kg m^2