Tutorial 4: Iterative control modelling of motor adaptation

For this tutorial you are given a folder containing **a main MATLAB script** that rely on several functions:

- Tutorial_4.m can be used to solve Question 2.

In this script, the section that you need to complete are marked with comments in capital letters and given defaults values. Please provide a solutions with required plots and explanations. Submit a Zip file (Tutorial4_Name_Surname.zip) containing:

- A PDF file containing answers for Question 1 and Question 2 (T4_answer.pdf)
- Your modified version of Tutorial_4.m. The script should work for part (a) and (b) in Question 2. (Tutorial_4.m)

Deadline: date 02/03/2023 time 23:59

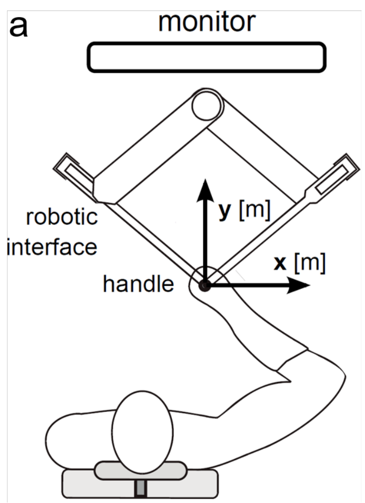

Figure 1: Motor adaptation of horizontal arm movements in a lateral force field - Experimental setup.

An experiment was conducted to investigate how humans adapt horizontal arm movements in an unknown force field. Figure 1 shows the experimental setup and Figure 2 the experimental results. The subject held the handle of a robotic device that provided force fields to the hand during planar arm movement and recorded the hand movement. Trials were carried out in five conditions:

Null field (NF) First, the subject performed 32 point-to-point reaching movements in the null-field (NF) condition, i.e. 0 force was programmed in the interface.

Velocity-dependent force field (VF) Next, the subject did continue to carry out reaching movements while the interface was programmed to apply a velocity-dependent force

$$\mathbf{F}_{\mathrm{VF}} = \begin{bmatrix} 0 & 25 \\ -25 & 0 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} N \tag{1}$$

where $\dot{x}$ and $\dot{y}$ are the velocities (m/s) in the x and y dimensions. The subject completed 127 movements in this condition.

Force channel In the third condition, the interface guides the movement along the $\{x = 0\}$ line through the haptic channel

$$\mathbf{F}_{\mathrm{c}} = \begin{bmatrix} -10000\,x \\ 0 \end{bmatrix} N. \tag{2}$$

The force channel constrains the subject's movement laterally (in x), but not in the movement direction y. The subject carried out 150 force channel trials.

Re-testing VF Then the subject completed again 12 reaching movements in the VF to test the retention of adaptation to the VF.

Washout NF Finally, the subject performed 26 reaching movements in NF to observe their re-adaptation to the "free" environment.

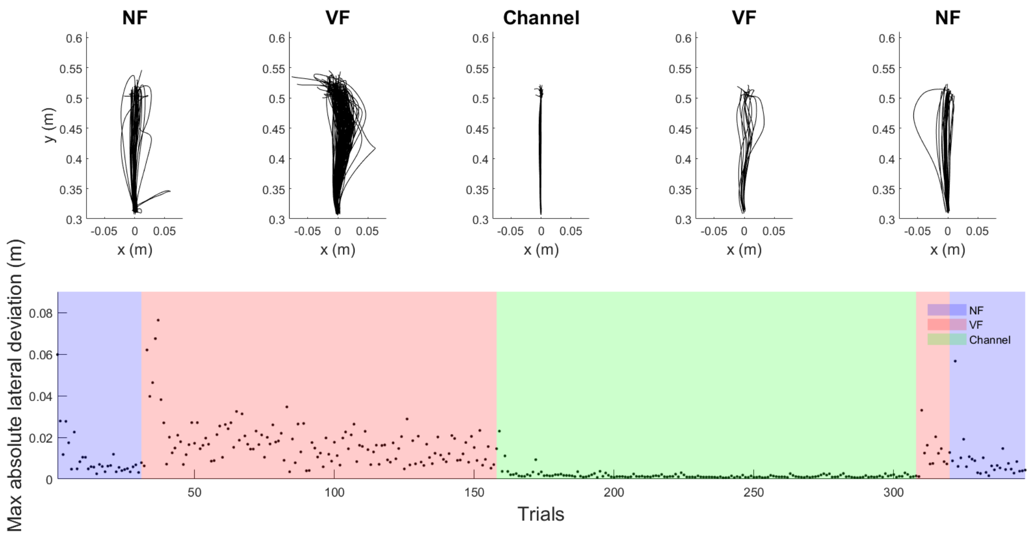

Figure 2: Motor adaptation of horizontal arm movements in a lateral force field. (a) paths in repeated reaching arm movements in five different phases with different force fields, and (b) maximum absolute lateral deviation during these phases.

Question 1: Experiment (40 marks)

(a) Describe the results of the study as they can observed from Figure 2. In particular what is the effect of the different phases on the maximum absolute lateral deviation.

[20 marks]

(b) Justify whether the channel hinders the retention of the motor adaptation in the first VF condition. In your answer provide an neuroscientific explanation of your findings.

[20 marks]

Question 2: Computational modelling (60 marks)

A proportional-derivative feedback controller guides the arm along a pre-defined straight-line trajectory, as in the NF condition in the data. If the motion of the arm is disturbed, the controller will send motor commands to the joints to stay along the NF trajectory. If the disturbance is similar trial after trial, these motor commands from the feedback controller can be gradually identified, i.e. a series of *feedforward (FF) motor commands* can be learned iteratively from the feedback motor commands.

For each shoulder and elbow joints, the feedback motor commands sent to this joint will be

$$u_{\mathrm{FB}}(t) = Pe(t) + D\dot{e}(t) \tag{3}$$

where P and D are the proportional and derivative gains, and $e(t) = q_d(t) - q(t)$ is the difference between the desired ($q_d(t)$) and current ($q(t)$) joint angles at time t. The feedforward command along the movement at trial j will be given by

$$u^1_{\mathrm{FF}}(t) \equiv 0\,, \quad u^{j+1}_{\mathrm{FF}}(t) = \alpha\, u^j_{\mathrm{FB}}(t) + (1-\gamma)\, u^j_{\mathrm{FF}}(t) \;\; (j \geq 1)\,, \tag{4}$$

where u^j_{FB} is the feedback command at the j^{th} trial, $\alpha, \gamma > 0$ are rates of change (you will see their effects in the question). The total motor command sent to the joint at trial j is

$$u(t)^j = u_{\mathrm{FB}}(t)^j + u_{\mathrm{FF}}(t)^j\,. \tag{5}$$

(a) Implement the nonlinear feedforward control in eqs.(3-5) for both the shoulder and elbow joints to follow the given desired trajectory *NFTraj* in the code. Use the values of $\alpha \equiv 0.08$ and $\gamma \equiv 0.001$ for your feedforward controller. You must simulate the trials in **all conditions** (the number of trials in each condition is predefined in the MATLAB code) and create the same plot as Figures 2a&b.

Note: the MATLAB script has the variables *NFTraj* and *qDesired* which conveniently contain the desired trajectory in Cartesian and joint coordinates (refer to the top of Tutorial4.m to see what is contained in each row).

[20 marks]

(b) Repeat your simulations with multiple different values for α and γ. Describe how these two parameters affect your simulations, using maximum lateral deviation plots to support your argument.

[20 marks]

(c) What is different between the maximum absolute lateral deviation in the data and your simulation in Q2(a) in the washout NF condition? How could the parameters α and γ describe this difference?

[20 marks]