Grading template for laboratory exercise 3
EL2820, Modeling of Dynamical Systems
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	Pass		Fail	
The report is handed in on time?		yes ☐	no ☐	
Number of authors		$\leq$ 2st ☐	$>$ 2 ☐	
Author names and personal identity number filled out?		yes ☐	no ☐	
The report is well structured? The language is understandable?	yes ☐	often ☐	sometimes ☐	no ☐
The figures are clear? (Captions, high resolution, etc.)	yes ☐	often ☐	sometimes ☐	no ☐
The preparation task is solved and motivated?		yes ☐	no ☐	
The working region is defined and motivated?		yes ☐	no ☐	
The sampling time is defined and motivated?		yes ☐	no ☐	
A detailed description of the input signal is given and the choice is motivated?		yes ☐	no ☐	
The amount of data used for estimation and validation is specified?		yes ☐	no ☐	
Models of more than one model structure have been estimated?		yes ☐	no ☐	
The model order of each model is motivated?		yes ☐	no ☐	
A ranking of the estimated models have been made?		yes ☐	no ☐	
The ranking is well motivated according to the requirements?		yes ☐	no ☐	

	Pass	Fail	
First review	☐	☐	Sign:
Second review (if failed in the first review)	☐	☐	Sign:

Pass

Signature:

1 Preparation task

This section should include:

- derivation of a physical model of the magnetic levitator in state-space form.

$$
\begin{aligned}
m\ddot{z} &= r\dot{z} + E_r - F_{ul} - mg \\
m\ddot{y} &= r\dot{y} - E_a + F_{lu} - mg \\
F_{ul} &= F_{lu} = Cm\frac{1}{(y-z)^4} \\
B &= \mu_0 \frac{Nr^2 I(t)}{2y^3} \\
E &= \frac{1}{2}A\frac{B^2(t)}{\mu_0} \\
E &= \frac{AN^2\mu_0 r^4}{8}\frac{I^2(t)}{y^6(t)} = Km\frac{I^2(t)}{y^6(t)} \\
E_a &= Km\frac{I^2(t)}{y^6(t)} \qquad E_r = Km\frac{I^2(t)}{z^6(t)} \\
\dot{a} &= \frac{r}{m}\dot{z} + K\frac{I^2}{z^6} - C\frac{1}{(y-z)^4} - g \\
\dot{b} &= \frac{r}{m}\dot{y} + K\frac{I^2}{y^6} - C\frac{1}{(y-z)^4} - g \\
\dot{z} &= a \qquad \dot{y} = b \\
x &= \begin{bmatrix} a \\ b \\ z \\ y \end{bmatrix} \qquad \dot{x} = \begin{bmatrix} \dot{a} \\ \dot{b} \\ \dot{z} \\ \dot{y} \end{bmatrix} = 0 = \begin{bmatrix} f_1(a\ b\ z\ y\ I) \\ \vdots \\ f_4(a\ b\ z\ y\ I) \end{bmatrix} \\
\dot{X} &= AX + BI(t) \\
A &= \begin{bmatrix} \frac{\partial f_1}{\partial a} & \cdots & \frac{\partial f_1}{\partial I} \\ \vdots & \ddots & \vdots \\ \frac{\partial f_4}{\partial a} & \cdots & \frac{\partial f_4}{\partial I} \end{bmatrix} = \begin{bmatrix} \frac{r}{m} & 0 & -\frac{4C}{(y-z)^5} - \frac{6KI^2}{z^7} & \frac{4C}{(y-z)^5} \\ 0 & \frac{r}{m} & \frac{4C}{(y-z)^5} - \frac{6KI^2}{z^7} & -\frac{4C}{(y-z)^5} \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \\
B &= \begin{bmatrix} \frac{\partial f_1}{\partial I} \\ \vdots \\ \frac{\partial f_4}{\partial I} \end{bmatrix} = \begin{bmatrix} \frac{2KI}{z^6} \\ -\frac{2KI}{z^6} \\ 0 \\ 0 \end{bmatrix}
\end{aligned}
$$

- suggestion for a suitable model order for a linear model (based on a linearization of the model)
- motivation for suggested model order.
- MATLAB codes for the required functions.

generateBinarySignal.m

```
function u = generateBinarySignal(alpha, lims, N)
    %% Initialization
    w = 2 * (rand(N,1) > alpha) - 1;
    u = zeros(N,1);

```

```
    %% Initial value of u
    if w(1) == -1
        u(1) = lims(2);
    else
        u(1) = lims(1);
    end

    %% Rest values of u
    for i = 2 : N
        if w(i) == -1
            if u(i-1) == lims(1)
                u(i) = lims(2);
            else
                u(i) = lims(1);
            end
        else
            u(i) = u(i-1);
        end
    end
end
```

getAverage.m

```
function bar_v = getAverage(v, tail)
    bar_v = mean(v(length(v)*tail/100 + 1 : end));
end
```

getStationaryAverages.m

```
function bar_y = getStationaryAverages(y_step, Nwr, tail)
    wrLen = length(y_step)/Nwr;
    for i=1:Nwr
        bar_y(i) = getAverage(y_step((i-1)*wrLen+1:(i)*wrLen),tail
            );
    end
end
```

findWorkingRegion.m

```
close all; clear all; clc;
%% Initialization
Ts = 0.001;
t = 0;
i = 1;
maxCurrent = 10;
stairHeight = 0.1;
stairDuration = 0.2;

%% Create Stair Signal
stairSignal(i) = 0;
while true
    t = t + Ts;
    i = i + 1;
    if t < stairDuration
        stairSignal(i) = stairSignal(i-1);
    else
        if stairSignal(i-1) + stairHeight > maxCurrent
```

```
            break
        end
        stairSignal(i) = stairSignal(i-1) + stairHeight;
        t = 0;
    end
end
t = 0 : Ts : (length(stairSignal)-1) * Ts;
t = t.';
stairSignal = stairSignal.';

%% Plot Stair Signal and Time
figure
plot(t,stairSignal)
xlabel('Time (s)')
ylabel('Stair Input (A)')

%% Input Signal Amplitudes
averagedU = getStationaryAverages(stairSignal, (maxCurrent/stairHeight+1), 0.6);

%% Conducting Experiment
y = getData(stairSignal, Ts);

%% Averaged Output Signal
averagedY = getStationaryAverages(y, (10/stairHeight+1), 0.6);

%% Plot to Find Working Region
figure
plot(averagedU,averagedY);
xlabel('Input (A)')
ylabel('Output (m)')
```

- one plot for the spectrum of the binary random signal for the required values of α.

Hint: This section should fit in 1-2 pages. You don't need to explain theory here.

2 Working region

This section should include:

- chosen working region.
- motivation for working region.
- plot illustrating working region, for example as shown in Fig. 1. (Always reference all figures in the text and use captions.)

3 Sampling time

This section should include:

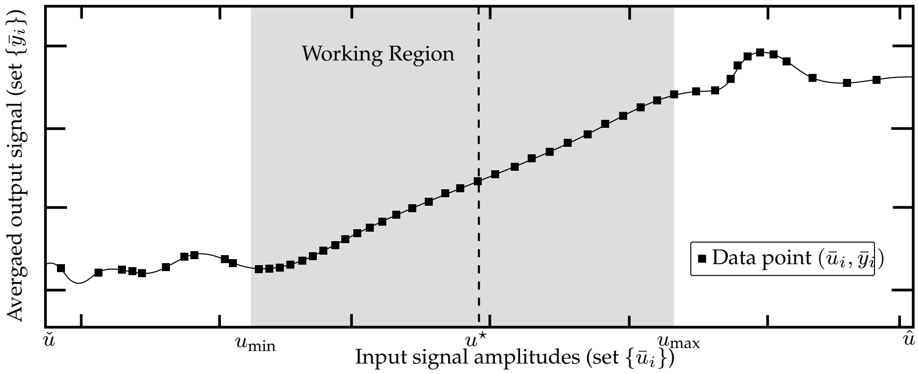

Figure 1: Example of how to choose the working region.

- sampling time.
- motivation for sampling time.
- plot of step responses yielding sampling time.

4 Input signals

This section should include:

- characteristics of chosen input signals.
- motivation for chosen input signals.

5 Estimation and validation data

This section should include:

- information about the amount of data used for identification and validation.

6 Models

This section should include:

- descriptions of model structures used. (You should use more than one structure.)
- motivation for choice of model order for each model structure.
- plots of Bode diagrams, poles and zeros.
- analysis/interpretations of plots.
- validation performed with simulation (`compare` with `M=inf`) and correlation analysis (`resid`).

- analysis/interpretations of validation and correlation analysis.
- a comparison between the accuracy of models obtained with different input signals (binary random signals v/s uniformly distributed white noise)
- a ranking of estimated models with respect to how well they describe the process, along with a rigorous motivation of chosen ranking. (Compare the analysis of plots, validation and correlation analysis for the different models.)

Note that the report is not in the format of a conference or journal paper. However, the language should be correct, concise and understandable. The figures should be clear, have captions, labels and be referenced in the text. All equations should be punctuated appropriately. (Equations are considered as part of sentences and should be treated accordingly.) All introduced symbols must be defined.