Sirius University of Science and Technology

Scientific Center for Information Technologies and Artificial Intelligence

Assignment on System Identification in MATLAB

Author: Artem Kondratev

E-mail: artemkondratev5@gmail.com

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1 Introduction

The task is to simulate two continuous-time dynamic systems, collect sampled input-output data (using different inputs) and process the collected data to estimate parameters of the simulated systems with the help of system Identification Toolbox of Matlab.

2 Methods

The birthday was used to derive unique dynamic systems parameters:

birthday: 10.09.2002

$$p = 1, \quad q = 0, \quad r = 0, \quad s = 9 \tag{1}$$

$$a = \frac{1}{p+q} = 1, \quad b = r + s = 9, \quad c = p + q + r + s = 10 \tag{2}$$

Two block diagrams for dynamic systems were implemented. The first block diagram (shown in Figure 1) is described by the formula:

$$H_1 = \frac{a}{s + ab} = \frac{1}{s + 9} \tag{3}$$

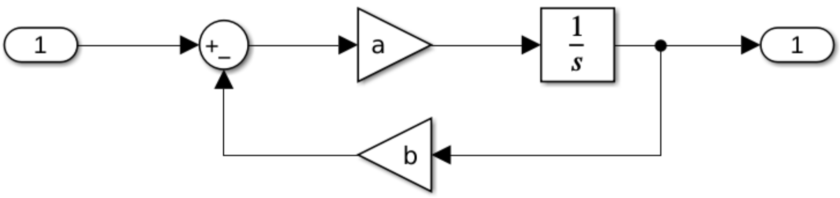

Figure 1: The first block diagram

The second block diagram is shown in Figure 2 and described as follows:

$$H_2 = \frac{a}{s^2 + abs + ac} = \frac{1}{s^2 + 9s + 10} \tag{4}$$

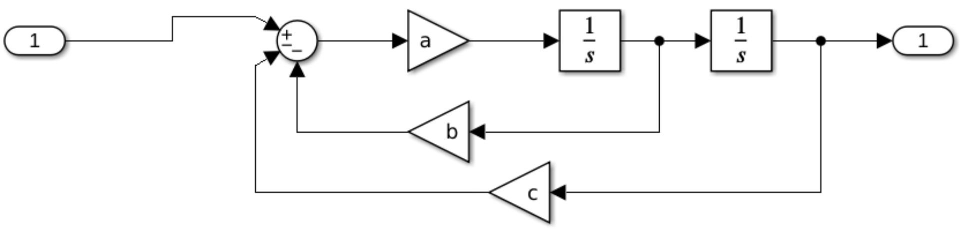

Figure 2: The second block diagram

The set of input signals includes:

- Several sinusoidal signals with amplitude 4 and frequencies 4, 8, 12, 16 s^{-1}
- Random value signal: $-4 \le value \le 4$
- Step signal with amplitude 2 for validation

Block diagram for creating signals is shown in Figure 3. A full dynamic model is shown in Figure 4.

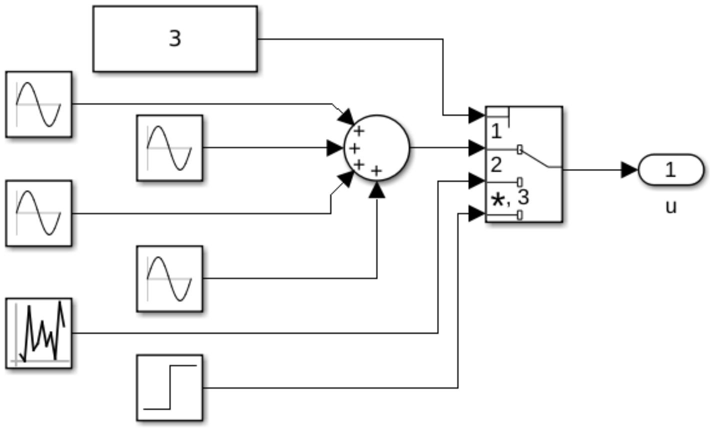

Figure 3: Input signals generator

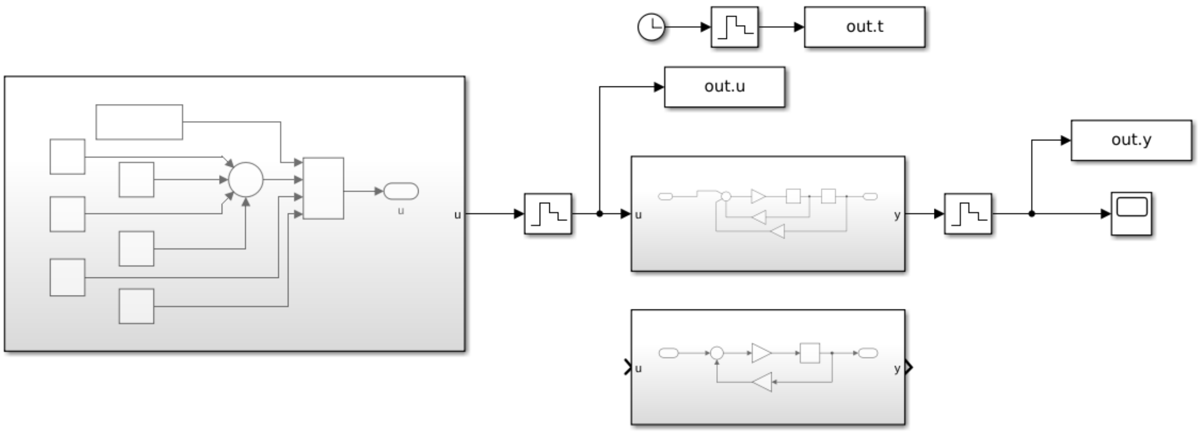

Figure 4: Continuous-time dynamic model

System Identification Toolbox used to find transfer functions from input and output datasets. The main window is shown in Figure 5. Poles and zeros of requested transfer functions are required. The first block diagram has no zeros and one pole:

$$s_1 = -ab = -9 \tag{5}$$

The second block diagram has no zeros and two poles:

$$s_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a} = -7.70, \qquad s_2 = \frac{-b + \sqrt{b^2 - 4ac}}{2a} = -1.30 \tag{6}$$

Both systems have negative poles, so they are stable.

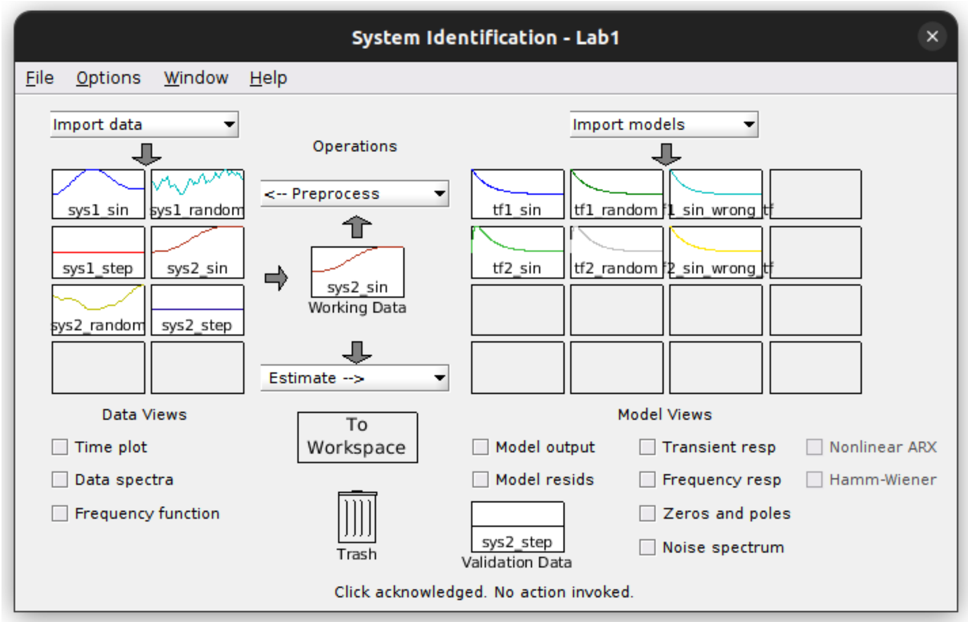

Figure 5: System Identification Toolbox

3 Results

System identification results for block diagram 1 are presented below. Transfer function, which identified by using several sinusoidal signals, is shown in Figure 6. The identification from the random value signal is shown in Figure 7. Both results match with analytical transfer function (3).

```
  From input "u1" to output "y1":
    1
  -----
  s + 9
Name: tf1 sin
Continuous-time identified transfer function.

Parameterization:
   Number of poles: 1   Number of zeros: 0
   Number of free coefficients: 2
   Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

Status:
Estimated using TFEST on time domain data "sys1 sin".
Fit to estimation data: 100% (stability enforced)
FPE: 1.608e-20, MSE: 1.598e-20
```

Figure 6: Transfer Function estimation for system 1 from sin input/output

```
  From input "u1" to output "y1":
    1
  -----
  s + 9
Name: tf1 random
Continuous-time identified transfer function.

Parameterization:
   Number of poles: 1   Number of zeros: 0
   Number of free coefficients: 2
   Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

Status:
Estimated using TFEST on time domain data "sys1 random".
Fit to estimation data: 100% (stability enforced)
FPE: 2.948e-22, MSE: 2.93e-22
```

Figure 7: Transfer Function estimation for system 1 from random signal input/output

Estimation with wrong number of zeros and poles is presented in Figure 8. Identified model differs from analytical results.

```
  From input "u1" to output "y1":
             -3.274e15 s^2 + 1.236e17 s + 3.278e17
  -------------------------------------------------------
  s^4 + 3.262e15 s^3 + 1.693e17 s^2 + 1.587e18 s + 2.95e18
Name: tf1 sin wrong tf
Continuous-time identified transfer function.

Parameterization:
   Number of poles: 4   Number of zeros: 2
   Number of free coefficients: 7
   Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

Status:
Estimated using TFEST on time domain data "sys1 sin".
Fit to estimation data: 58.69% (stability enforced)
FPE: 0.03544, MSE: 0.03467
```

Figure 8: Estimation for system 1 with wrong number of poles and zeros

Step signal input and response used to validate estimated results. The validation results are shown in Figure 9. For identification results with correct number of zeros and poles fit to estimation data is 100%. For identification results with wrong parameters fit to estimation data is 90.26%.

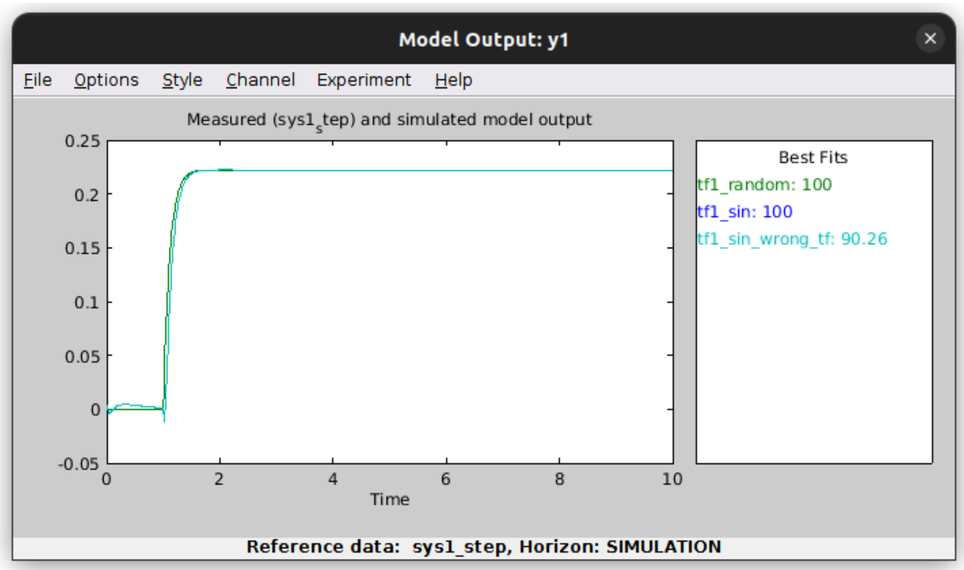

Figure 9: Validation results for system 1

System identification results for block diagram 2 presented below. Transfer function, which identified by using several sinusoidal signals, is shown in Figure 10. The identification from the random value signal is shown in Figure 11. Both results match with analytical transfer function (4).

```
  From input "u1" to output "y1":
         1
  -------------
  s^2 + 9 s + 10
Name: tf2 sin
Continuous-time identified transfer function.

Parameterization:
   Number of poles: 2   Number of zeros: 0
   Number of free coefficients: 3
   Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

Status:
Estimated using TFEST on time domain data "sys2 sin".
Fit to estimation data: 100% (stability enforced)
FPE: 1.002e-21, MSE: 9.917e-22
```

Figure 10: Transfer Function estimation for system 2 from sin input/output

```
  From input "u1" to output "y1":
         1
  -------------
  s^2 + 9 s + 10
Name: tf2 random
Continuous-time identified transfer function.

Parameterization:
   Number of poles: 2   Number of zeros: 0
   Number of free coefficients: 3
   Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

Status:
Estimated using TFEST on time domain data "sys2 random".
Fit to estimation data: 100% (stability enforced)
FPE: 2.465e-23, MSE: 2.44e-23
```

Figure 11: Transfer Function estimation for system 2 from random signal input/output

Estimation with wrong number of zeros and poles is presented in Figure 12. Identified model differs from analytical results.

```
  From input "u1" to output "y1":
   0.09162
  ----------
  s + 0.5732
Name: tf2 sin wrong tf
Continuous-time identified transfer function.

Parameterization:
   Number of poles: 1   Number of zeros: 0
   Number of free coefficients: 2
   Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

Status:
Estimated using TFEST on time domain data "sys2 sin".
Fit to estimation data: 55.87% (stability enforced)
FPE: 0.001848, MSE: 0.001836
```

Figure 12: Estimation for system 2 with wrong number of poles and zeros

Step signal input and response used to validate estimated results. Validation is shown in figure 13. For identification results with correct number of zeros and poles fit to estimation data is 100%. For identification results with wrong parameters fit to estimation data is 22.5%.

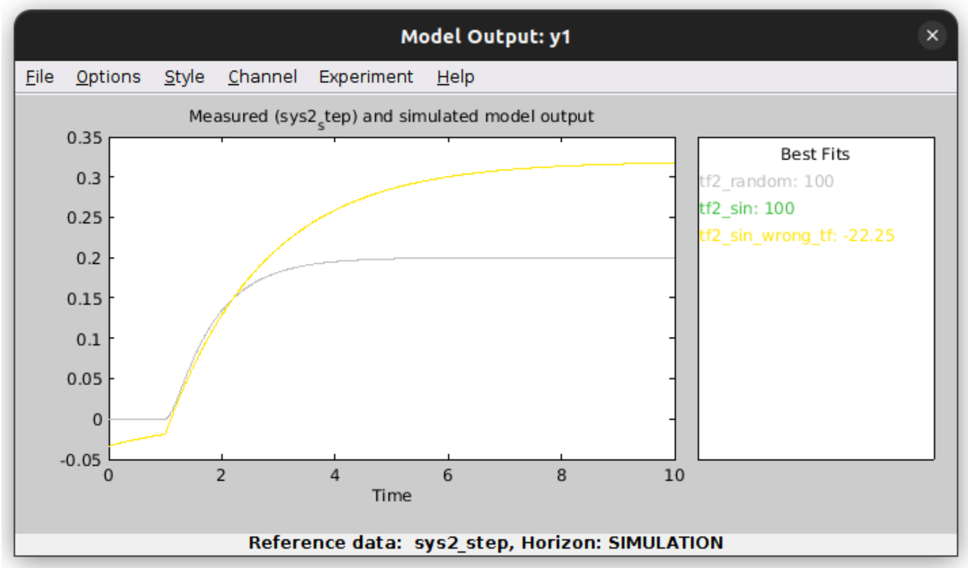

Figure 13: Validation results for system 2

4 Discussion

System identification with correct transfer function structure is very accurate for first-order and second-order continuous-time dynamic systems. Estimation fit for these cases is 100%. Using wrong transfer function structure for system identification results in a low-precision fit (less than 50%).

Using validation allows to find estimation errors quickly and helps identify errors in transfer function model. This is a good approach for checking model quality.

System Identification Toolbox is a powerful tool for estimating unknown model parameters using input and output arrays of signals only.

References

1. MathWorks, "To Workspace," *Simulink Documentation*. [Online]. Available: https://se.mathworks.com/help/simulink/slref/toworkspace.html. [Accessed: Nov. 19, 2024].