Manual for MFDID Program Including Numerical Example

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This manual presents how to use the MFDID program for system identification through a numerical example developed from the experimental data of a three degree-of-freedom (DOF) shear building with active tendons at the first floor (Chung et al. 1989; Dyke et al, 1995). The detailed parameters of the model are given in Table 1 of L.L. Chung et al. (1989) and Example 2 of Dyke et al. (1995).This MFDID program is developed for MATLAB and was found to be available up to the version R2012b.

Preliminary Steps: Data Preparation

Step 1. ***run Make_SYS.m***

- ✓ This m file contains the information of the 3 DOF shear building. Running this file will construct the analytical models with and without the active tendons and subsequently realize state-space models required for analysis.
- ✓ The state-space models are saved in ABCD.mat

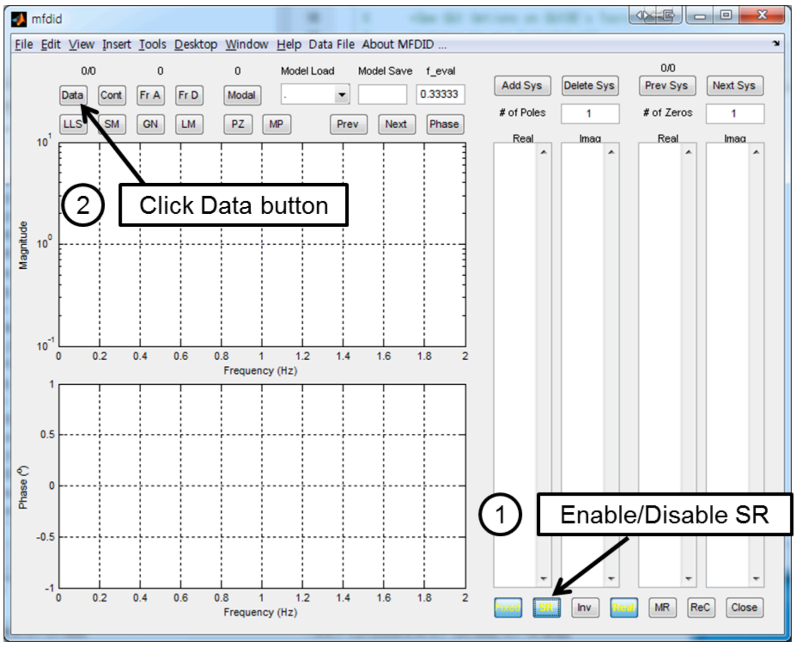
Step 2. ***run Get_pexdata.m***

- ✓ Running this file generates pseudo-experimental data from the analytical model built in Step 1. The inputs of the transfer functions (TFs) are ground excitation and control force and the outputs are displacement of the first story, acceleration of each of the three stories, ground excitation and control force. All the TFs are also duplicated with added noise of 15%. Therefore, 4 groups of TFs are created: TFs for ground excitation, TFs for ground excitation with added noise, TFs for control force, TFs for control force with added noise. The TFs are saved in pexdata.mat

Step 3. ***run Run_MFDID.m***

- ✓ Running this file loads the TFs built in Step 2. The TFs are grouped in three categories: TFw - TF from ground excitation (SIMO system), TWu - TF from control force (SIMO system) and TF - TF from both ground excitation and control force (MIMO system). Then it will run the mfdid.m file to open the GUI window shown below.

✓ If Steps 1 and 2 have been run previously, the results are saved as mat files so that you don't need to run Steps 1 and 2 again. Executing Run_MFDID.m will load the saved mat files.

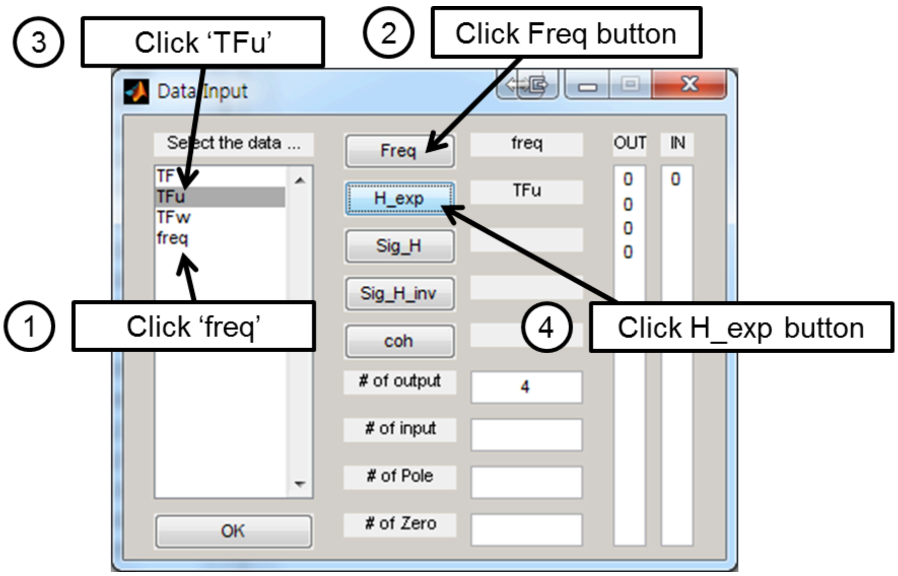


[Initial GUI window of MFDID]

Main Steps: How to Use the GUI

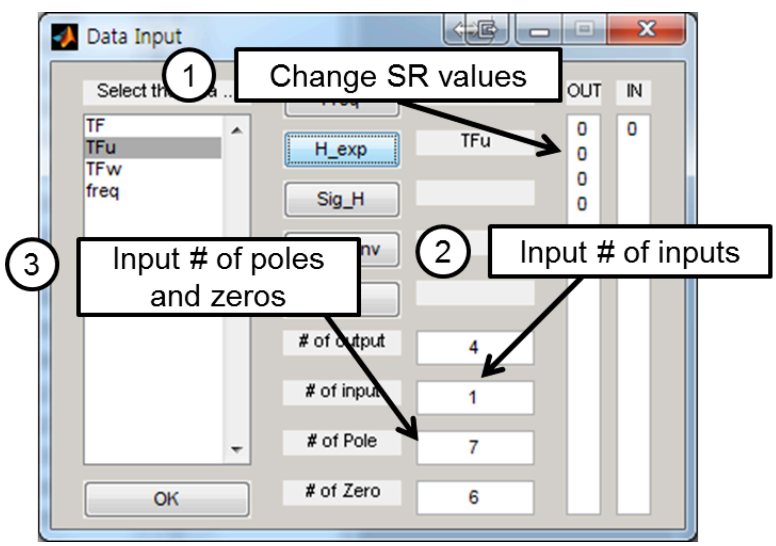
1. Check the **SR** button in the GUI to enable/disable the SR (Structural Relationship) option. For additional details about SR, please see Kim et al. (2005).
   A. In most cases, the results from MFDID are reasonable without using the SR option.
   B. When the number of zeros at the origin is known, the SR option can be enabled to get more reasonable results with physical meaning.
   C. When SR is enabled, refer to 4-A below to set SR details.

2. Click the **Data** button at the left top of the GUI to load input data for MFDID.



[Data Input window – before selecting the input data]

3. Select frequency vector and transfer function data for MFDID. The pseudo-experimental data generated in Steps 1-3 appears in the left box.
   A. Click freq (frequency vector) in the left box to shadow.
   B. Click **Freq** button to load freq vector.
   C. Click TFu (or any other transfer function vector) in the left box to shadow.
   D. Click **H_exp** button to load TFu vector.



[Data Input window – after selecting input data]

4. After setting the input data, the Data Input window shows the number of outputs in the **# of output** box. The same number of zeros (0) with the numbers of outputs and inputs will appear in the right **OUT** and **IN** boxes.

   A. If SR button was disabled, leave the zeros as they are (i.e., default). If the **SR** button was enabled (or you know the SR of the transfer functions), assign the corresponding values tabulated below in the **OUT** and **IN** boxes. If we do not know the SR, then leave the value as a default (i.e., zero).

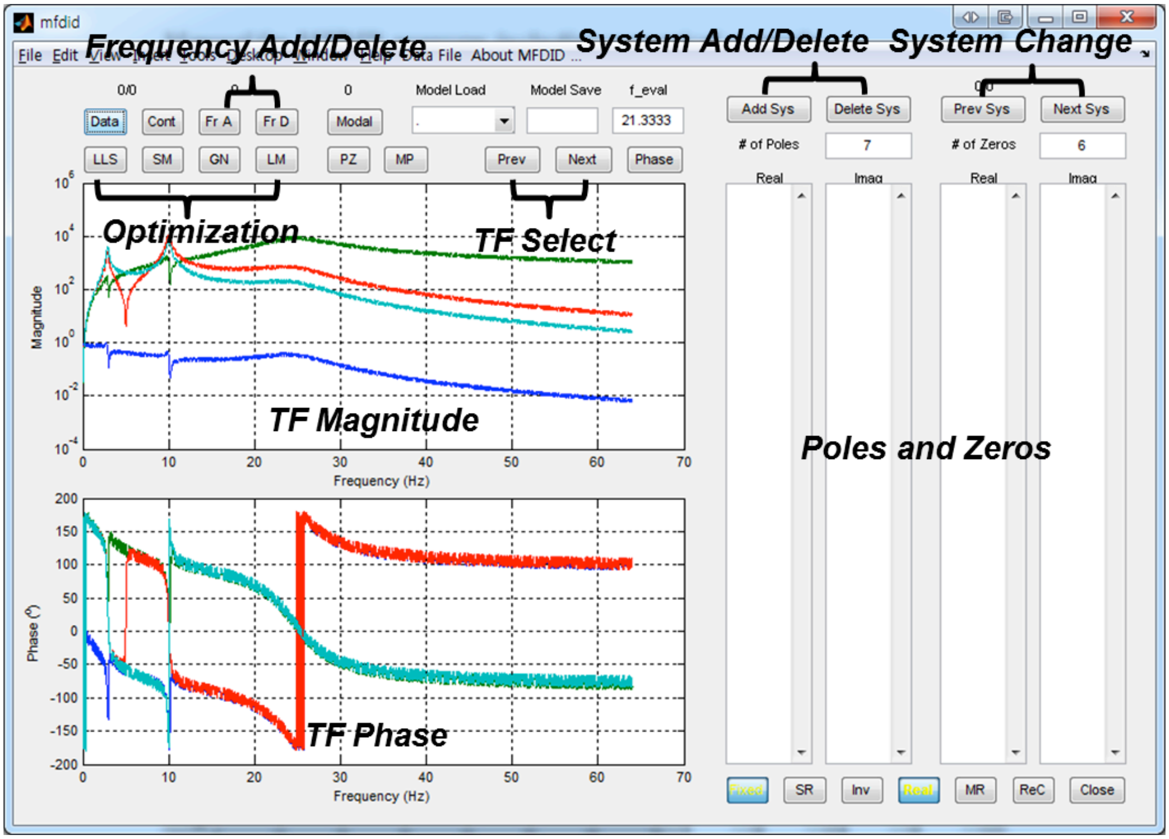
Input	Output	Structural Relationship	Input	Output	Structural Relationship
0	0	No relationship	2	0, 1	No zero at origin
1	0, 1, 4,	No zero at origin		2	1 zero at origin
	2, 5	1 zero at origin		3	2 zeros at origin
	3	2 zeros at origin		4, 5, 6	Identify matrix*
	6	4 zeros at origin			

*For improving fit with ground input to absolute acceleration output

   B. Input 1 in the **# of input** box as 1 (in the case of using TFu - SIMO system)

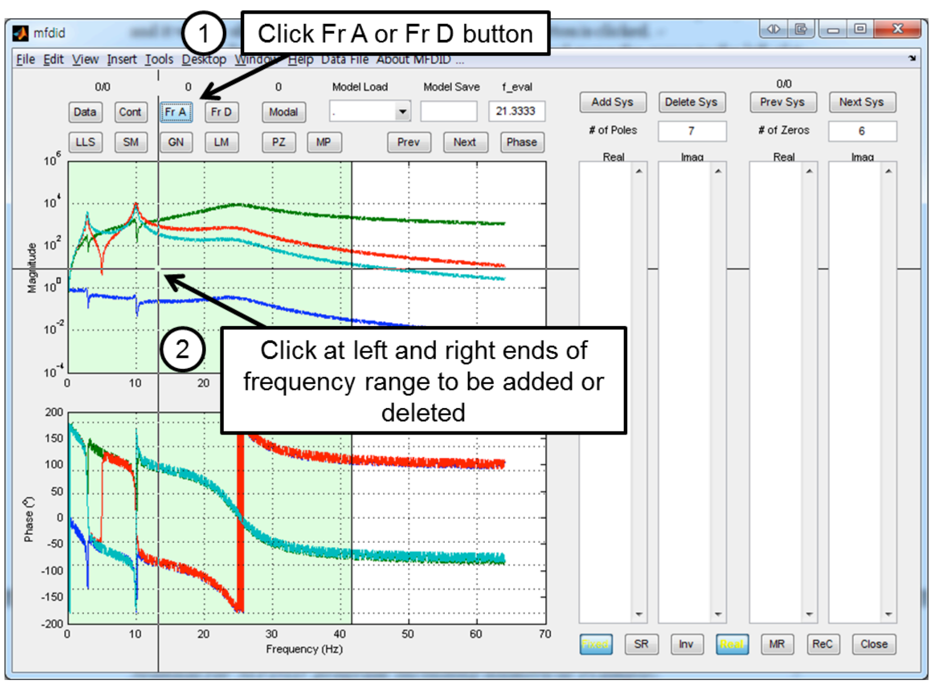
   C. Input the number of poles and zeros (7 and 6 in this example) in the **# of Pole** and **# of Zeros** boxes, respectively. If you do not know the number of poles and zeros, start with sufficiently large numbers and iteratively reduce the numbers during the optimization process within MFDID.

   D. Click **OK** button to launch the MFDID main GUI



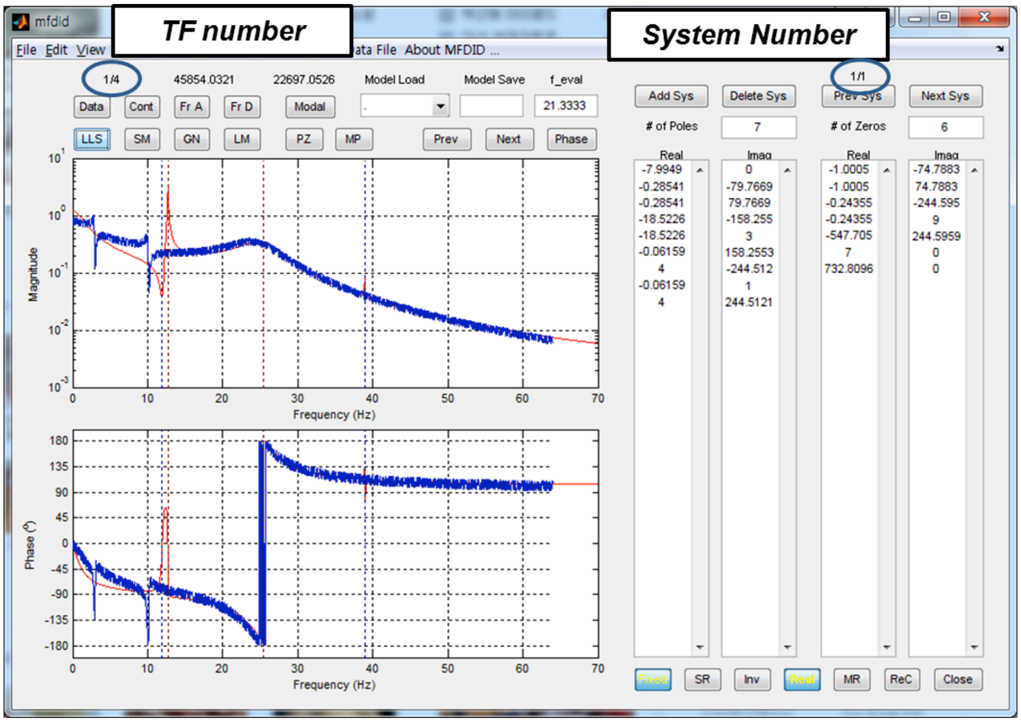
[MFDID main GUI window after data is loaded with elements highlighted]

5. The magnitudes and phase angles of the selected TFs will appear in the left boxes, whereas the number of poles and zeros are in the upper right boxes. The sequence of colors is the same as MATLAB (i.e., blue, red, green, cyan, …).
   A. The optimization can be performed within a certain frequency range of experimental data. Before running the optimization process, the frequency range can be adjusted using **Fr A** (add frequency range) and **Fr D** (delete frequency range) button. The default frequency range is set to [0, 41.6 (0.65 times of maximum frequency 64Hz)] and it will be shadowed in the plot boxes, when either button is clicked.
   B. To add frequency range, click **Fr A** button and move the cursor to within the plot boxes. A cross mark will appear. Click once each at your left and right ends of the frequency range and the resulting frequency range will appear with shadow.
   C. To trim frequency range, click **Fr D** button and move the cursor to within the boxes. A cross mark will appear. Click once each at your left and right ends of the frequency range and the resulting frequency range will appear with shadow.

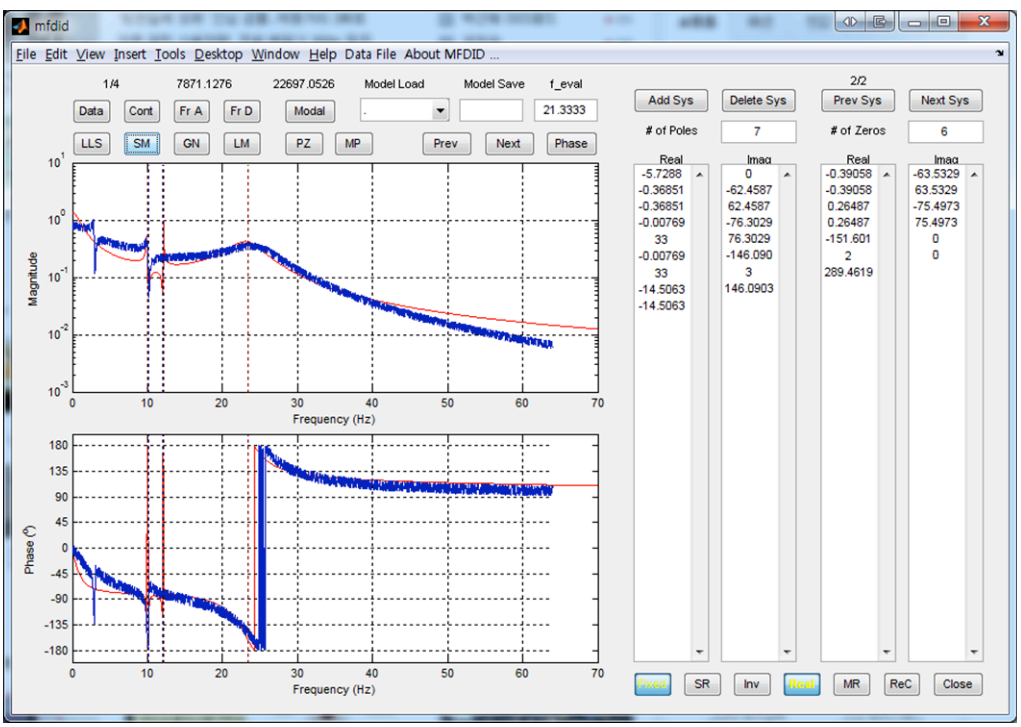


[Adjusting frequency range]

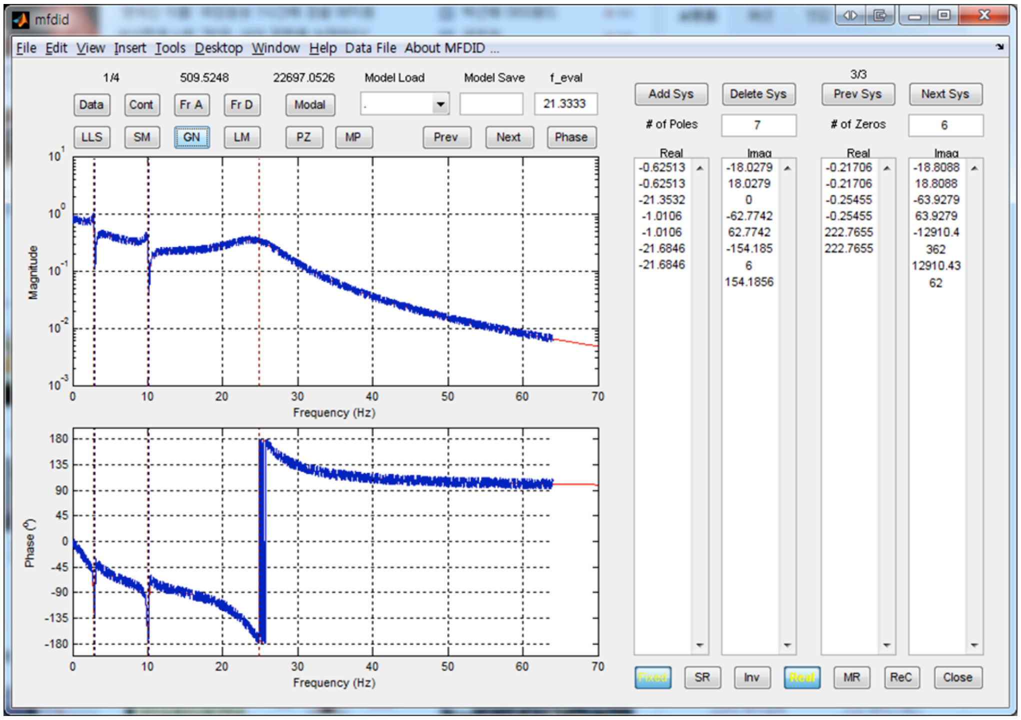
6. Click the optimization buttons (i.e., **LLS** (Linear Least Square method), **SM** (Steiglitz-McBride method), **GN** (Gauss-Newton method), and **LM** (Levenberg-Marquardt method) buttons) in order individually to optimize the poles and zeros. The objective function change during optimization will pop up in a separate window. Refer to Kim et al. (2005) for the details of the optimization algorithms.
   A. After each optimization, the estimated TF for the first output (e.g., displacement of the first story in this example) will be displayed in red line. The TFs for the other outputs can be selected using **Prev** and **Next** buttons. The poles and zeros of the estimated TF in display are tabulated in the right boxes.
   B. The resulting system (i.e., a group of TFs for all outputs) after each optimization will be stored temporarily. The stored system after each optimization can be reviewed using **Prev Sys** and **Next Sys** button.
   C. A system can be created or modified by inputting or reviewing poles and zeros given in the right boxes. The numbers in the **# of Poles** and **# of Zeros** boxes must be equal to the numbers of poles and zeros in the right boxes. The created or modified systems can be added in the list of the stored systems using **Add Sys** button. A stored system can be removed using **Delete Sys** button.
   D. If you want to keep some poles and zeros during optimization, enable **Fixed** button. Then prefix "f" the real values of poles and zeros and click **Add Sys** button. Then you can keep optimization with "f"ixed poles and/or zeros.



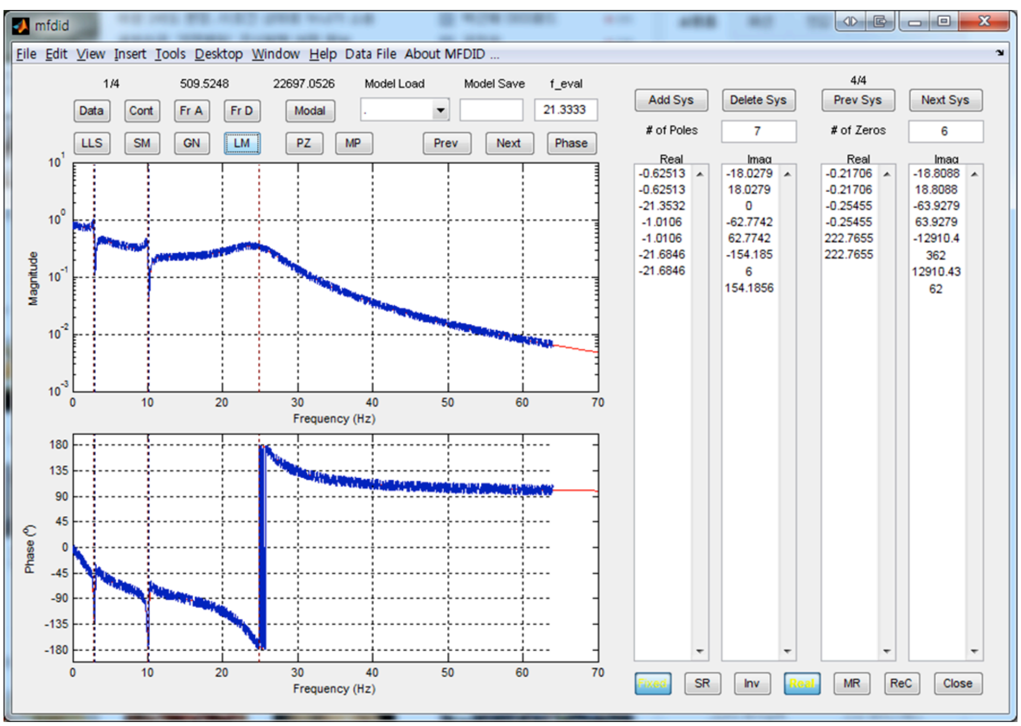
[After LLS (Linear Least Square method) optimization]



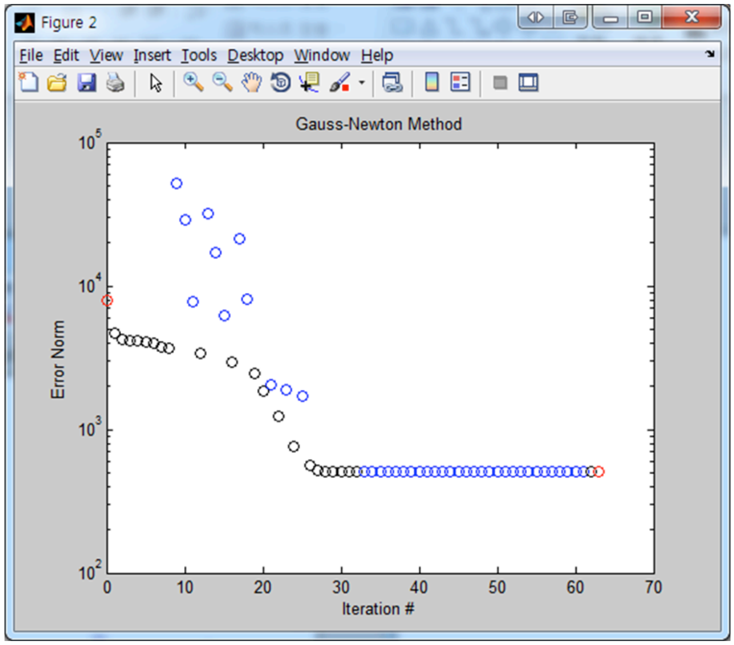
[After SM (Steiglitz-McBride method) optimization]



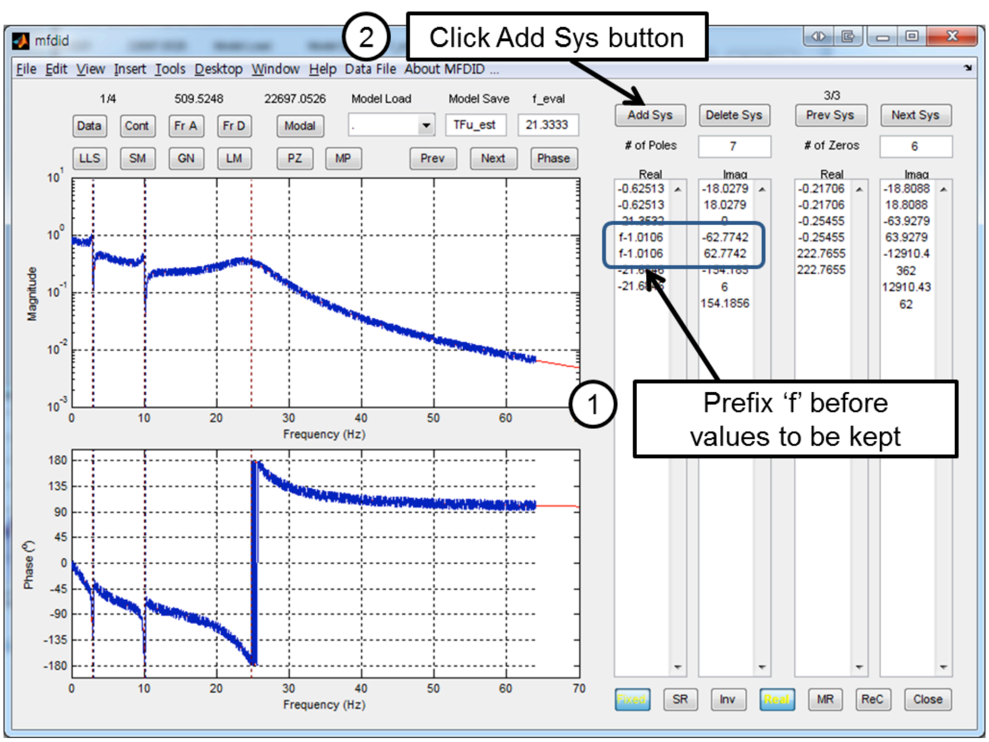
[After GN (Gauss-Newton method) optimization]



[After LM (Levenberg-Marquardt method) optimization]



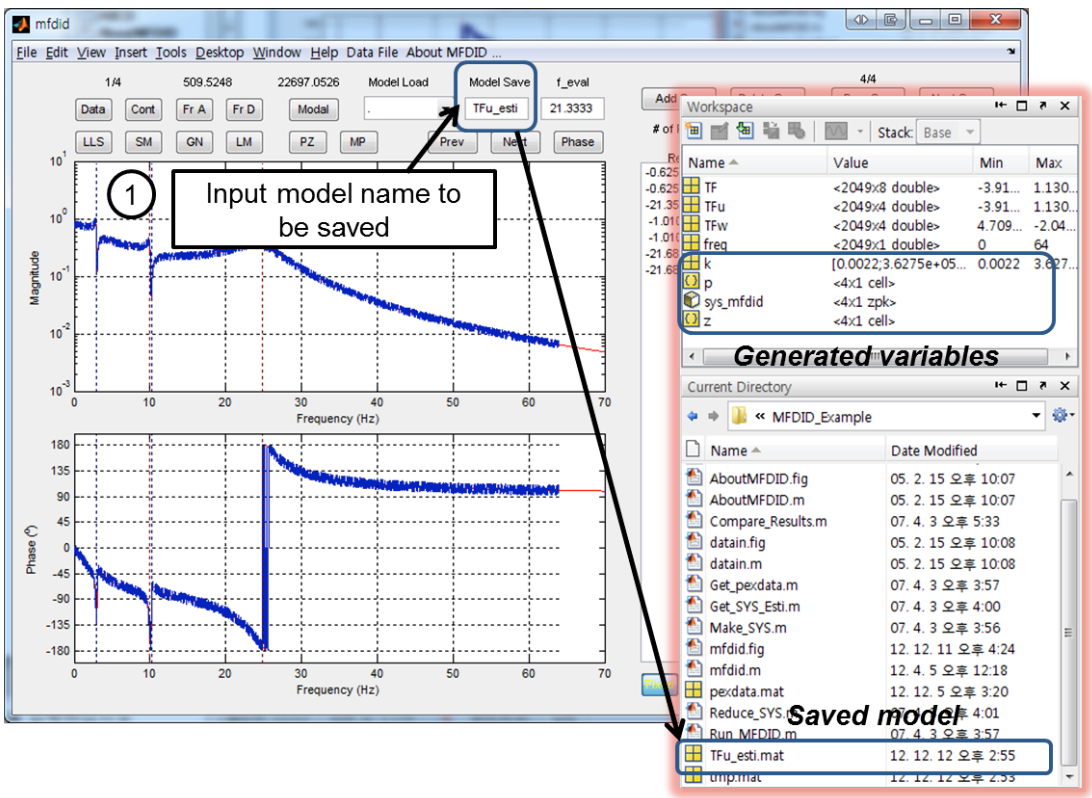
[Objective function change pop-up window]



[Keeping poles and/or zeros fixed]

7. After the estimated system has been developed, you can save the estimated system by inputting a model name (e.g., TFu_esti) in the **Model Save** box at the top of the main GUI.
   A. Then variables regarding zeros (z), poles (p), gains (k), and a continuous-time zero/pole/gain model (sys_mfdid) of the system will be created in the Workspace of MATLAB, and saved as a mat file with the name input in the **Model Save** box.
   B. You can use **Model Load** box to load the saved zero/pole/gain model of the system in 7-A.

8. In the case of MIMO system, repeat previous steps for the number of inputs of the transfer function.



[Saving optimized (estimated) system]

The Other Buttons in the GUI

Main GUI window	
Cont	Not Used
Modal	Shows natural frequency and damping of selected poles or zeros and displays natural frequencies and damping of all poles and zeros in the command window
f_eval	Frequency at which magnitude is matched exactly
PZ	Pop-up pole-zero plot of estimated TF
MP	Not Used
Phase	Wraps phase ($[-\pi, \pi]$ -> $[0, 2\pi]$)
Inv	When enabled, constructs the objective function of optimization using inverse of given TF (to accurately estimate poles and zeros near the origin)
Real	When enabled, optimization is executed to fit only real values for poles and zeros
MR, Rec	Not Used
Close	Close main GUI window
Data window	
Sig_H	Input weighting function evaluated at each frequency point (input the vector with the same number of entries with the frequency vector)
Sig_H_inv	Input weighting function evaluated at frequency point when **inv** button is enabled (input the vector with the same number of entries with the frequency vector)
coh	Not known

Post-Processing Steps: Case Study

In these post-processing steps, the MFDID results obtained from SIMO and MIMO systems will be compared. The system matrices from two SISO systems (i.e., SIMO system from ground excitation and SIMO system from control force) are diagonally augmented (i.e., MIMO1) to be compared with the original MIMO system (i.e., MIMO2).

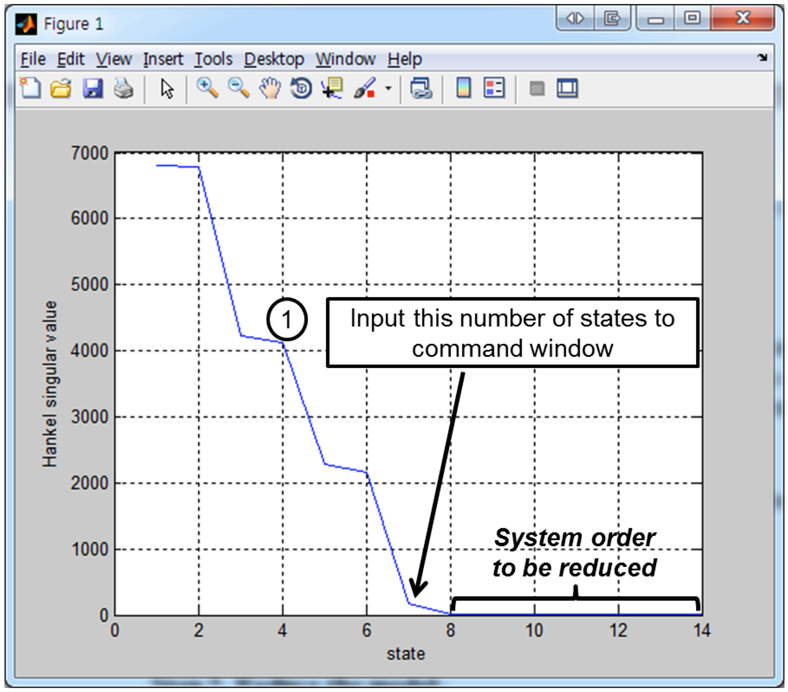
To follow these steps, you need to have run the previous steps (preliminary step and main step) to estimate three systems: system for ground excitation (SIMO), system for control input (SIMO), and both (MIMO). The example result files are given as TFw_esti.m, TFu_esti.m, and TF_esti.m, respectively. Note that two SIMO systems will be diagonally augmented to construct MIMO1 to be compared with MIMO2, the original MIMO system.

Step 4. ***run Get_SYS_Esti.m***

- Before running this m file, open Get_SYS_Esti.m file and change the file names at lines 8, 17, 26 to those of estimated systems from ground excitation (SIMO), control input (SIMO), and both (MIMO), respectively (Currently, the file names are TFw_esti.m, TFu_esti.m, and TF_esti.m).
- Running this m-file will load the estimated zero/pole/gain models (i.e., sys_mfdid) of the three systems and subsequently realize state-space models.
- Then, the estimated state-space models of the three systems are saved in ABCD_ESTI.mat

Step 5. ***run Reduce_SYS.m***

- Running this m-file will load the state-space models in ABCD_ESTI.mat and construct a diagonally augmented system (MIMO1) using two SISO systems.
- Then singular value decompositions of the system matrix (i.e., A matrix) is performed for two MIMO systems to substantially reduce the models by removing the repeated poles.
- A plot with singular values according to the number of states will be popped up. In the command window, input the number of state to be retained (e.g., 7 in this example). Note that this procedure runs twice for the MIMO1 and MIMO2 systems.
- The reduced state-space models of both the MIMO1 and MIMO2 systems are saved in ABCD_ESTI_RED.mat



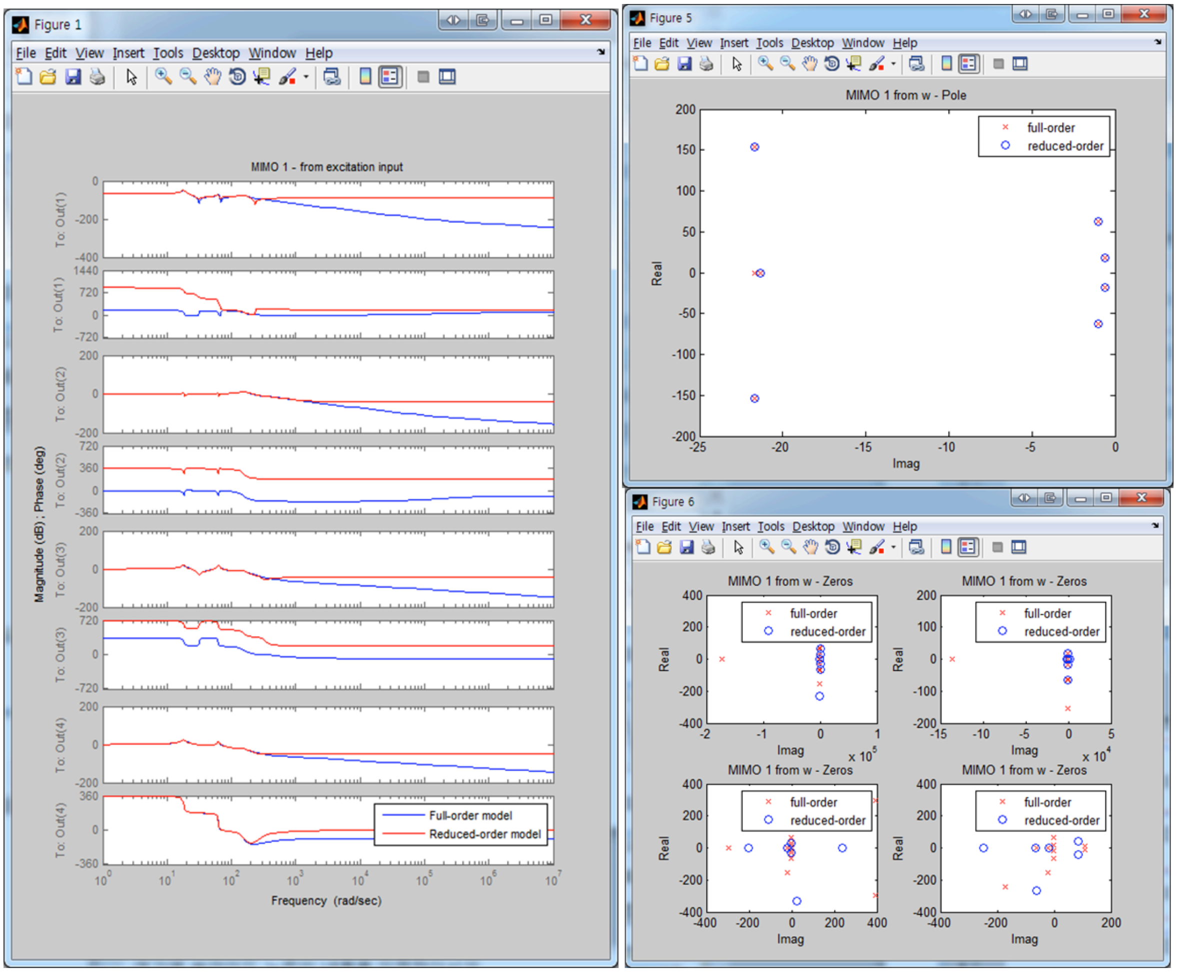
[Singular value pop-up window to determine retained system order (number of states)]

Step 6. ***run Compare_Results.m***

- Running this m file will load all full-sized and reduced models obtained in Steps 4 and 5 (i.e., ABCD_ESTI_RED.mat).

- Bode plots, pole-zero plans, and eigenvalues will be plotted or listed in the command window.

- Bode plots: Figures 1-4
- Pole-zero plans: Output Figures 5-12 for MIMO1 and MIMO2, Output Figures 13-16 for comparison of MIMO1 and MIMO2
- Eigenvalues: Listed in command window (Analytical model, MIMO1, and MIMO2)



[Examples of bode plots (left) and pole-zero plans (right)]

```
Command Window
Compare results of analytical model and esitmated model ...
Current plot held
Current plot held
Current plot held
Current plot held

tmp =

  1.0e+002 *

  -0.2169 + 1.5416i        0           -0.2168 + 1.5419i        0           -0.2171 + 1.5414i
  -0.2169 - 1.5416i        0           -0.2168 - 1.5419i        0           -0.2171 - 1.5414i
  -0.0101 + 0.6277i        0           -0.0101 + 0.6277i        0           -0.0101 + 0.6277i
  -0.0101 - 0.6277i        0           -0.0101 - 0.6277i        0           -0.0101 - 0.6277i
  -0.2130                  0           -0.2135                  0           -0.2127
  -0.0063 + 0.1804i        0           -0.0063 + 0.1803i        0           -0.0063 + 0.1805i
  -0.0063 - 0.1804i        0           -0.0063 - 0.1803i        0           -0.0063 - 0.1805i

==== Analtytical Model ====        ==== Estimated Model 1 ====          ==== Esitmated Model 2 ====

Compare results of analytical model and esitmated model ...Done
fx >>
```

[Eigenvalue listed in command window]

References

L. L. Chung, R. C. Lin, T. T. Soong, A. M. Reinhorn, (1989) "Experimental study of active control for MDOF seismic structures," Journal of Engineering Mechanics-ASCE, 115(8), 1609-1627.

S. J. Dyke, B. F. Spencer, Jr., P. Quast, M. K. Sain, (1995). "Role of control-structure interaction in protective system design," Journal of Engineering Mechanics-ASCE, 121(2), 322-338.

S. B. Kim, B. F. Spencer, Jr., and C-B. Yun, (2005). “Frequency Domain Identification of Multi-Input, Multi-Output Systems Considering Physical Relationships between Measured Variables,” Journal of Engineering Mechanics-ASCE, 131(5): 461-472