

Sshaper User's Manual

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Abstract

This note explains how to use the program **Sshaper** implemented in MATLAB to design a sensitivity function by frequency shaping. For theoretical explanation, see the paper

- “*Sensitivity shaping with degree constraint by nonlinear least-squares optimization*” by R. Nagamune and A. Blomqvist, submitted for publication (also available at <http://www.math.kth.se/~andersb/research/NBTechReport2.pdf>).

and references therein. Comments and questions are to be sent to andersb@math.kth.se and/or ryozo@me.berkeley.edu.

0 Let’s get started!

The following steps will get you started.

- Download zip-file `Sshaper1.0.zip` from www.math.kth.se/~andersb/software.html.
- Unzip the file into an own folder, e.g. `Sshaper`.
- Start MATLAB and change your current path to your new folder.
- Type `Sshaper` at the prompt. Then, the `Main Menu` appears as below.

```
-----  
Main Menu  
1. Input Data Menu  
2. Design Controller  
3. Load Controller for Comparison  
4. Plot Menu  
5. Print Menu  
6. Load Design  
7. Save Design  
8. Display Variables  
9. Clear Variables  
10. Close Figures  
11. Exit  
-----
```

Enter choice (11):

Now, you are up and running!

`Sshaper` is a terminal-based interface for designing a sensitivity function. Throughout the program, menus like the one above will appear. By simply pressing return (or enter) you choose the default option, in this case 11. In principle, repeated “returns” will bring you to the main menu and from there exit the program.

Below, it is explained what you can do by choosing from 1 to 11 in the `Main Menu`.

1 Input Data Menu

If you choose 1 in `Main Menu`, the following menu appears:

```
-----  
Input Data Menu  
1. Load Benchmark Example  
2. Plant  
3. Controller Requirements  
4. Desired Frequency Response and Weight  
5. Other Design Parameters  
6. Return to Main Menu  
-----
```

Enter choice (6):

1.1 Load Benchmark Example

There are two benchmark examples prepared.

- “Flexible Beam Control” in the book *“Feedback Control Theory”* written by Doyle, Francis and Tannenbaum, MacMillan Publishing Company, 1992.
- “Slide Drive Control” in the book *“Classical Control Using H^∞ Methods”* written by Helton and Merino, SIAM, 1998.

By loading each example, data necessary for controller design will be in the workspace.

1.2 Plant

The scalar plant must be named `sysP`, and it must be `tf`-format. This also includes a sampling time, which is zero if the plant is continuous-time.

If you choose 2 in **Input Data Menu**, you can see the current `sysP`:

```
-----
Currently your choices are
  Plant:
Empty transfer function.
-----
Do you want to change your input? (n)
If you want to input  $P(s) = (s + 1)/(s^2 + s + 2)$ , input as follows:
Do you want to change your input? (n) y
Do you want to load it from a file? (y)n
Give sampling time, 0 for continuous plants. 0
Give numerator [1 1]
Give denominator [1 1 2]
Then, you will see
-----
Currently your choices are
  Plant:

Transfer function:
   s + 1
-----
s^2 + s + 2
-----
Do you want to change your input? (n)
Continue until you see the right sysP.
  If you want to input a discrete-time plant  $P(s) = (z + 1)/(z^2 + z + 2)$  with sampling
period 0.5, input as follows:
Give sampling time, 0 for continuous plants. .5
Give numerator [1 1]
Give denominator [1 1 2]

  You can also load sysP from mat-file. Mat-file must be located in the same or one-
level-upper or one-level-lower directory. For example, we can make a mat-file plant.mat
as follows:
numP = [1 1];
denP = [1 1 2];
sysP = tf(num,den);
save plant sysP

To load sysP from a mat file, type y or press return when you are asked “Do you want
to load it from a file? (y)”.
```

1.3 Controller Requirements

You can specify the following:

- the relative degree of the controller
- the number of integrators ($1/s$ in continuous-time, $1/(1-z)$ in discrete-time) in the controller

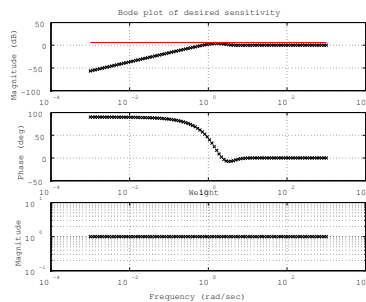
If we specify these, a controller satisfying these requirements will be designed automatically by “2. Controller Design.”

1.4 Desired Frequency Response and Weight

You can input/change “Desired frequency response and weight” here. Desired frequency response *must* be input before controller design. On the other hand, weight is set to be $[1, 1, \dots, 1]$ as a default. You will see the following message with a figure:

```
-----  
Currently your choices are  
displayed in Figure 1  
-----
```

Do you want to change your input? (n)



This figure indicates all the current design parameters that you are choosing. The three plots correspond respectively to:

- Uppermost figure: Gain plot of S_{desired} at θ . (The horizontal line indicates the level γ , the uniform bound of the gain.)
- Middle figure: Phase plot of S_{desired} at θ .
- Lowermost figure: Plot of weight .

To modify the current values of θ , S_{desired} and weight , you type a character other than (n).

1.4.1 Changing θ

First, you can change the gridding θ with the menu:

```
-----  
Gridding  
1. Load from file  
2. Give condensed  
3. Give manually  
4. Keep current  
-----
```

Enter choice (4):

1. Load from file: You can load θ from a file in which a vector θ is stored.
2. Give condensed: You can specify the lower limit, the upper limit, and the number of points of θ :

Give lower limit (rad/sec): ([0.001])
Give upper limit (rad/sec): ([1000])
Give number of points: ([100])

This is same as `logspace(-3,3,100)`.

3. Give manually: You can type the vector `theta` directly; for example, `logspace(-3,3,100)`.
4. Keep current: `theta` is unchanged.

1.4.2 Changing `Sdesired` and `weight`

After specifying `theta`, you can specify/change `Sdesired` and `weight`. There are several ways to do this:

```
-----  
                Desired Sensitivity and Weight  
1. Load from file  
2. Give ideal  
3. Use previously designed S  
4. Give manually  
5. Give manually in region  
6. Give manually by window  
7. Give Interactively in Plot  
8. Keep current  
-----
```

Enter choice (8):

1. Load from file: You can load `Sdesired` and `weight` from a file in which those vectors are stored.
2. Give ideal: You can specify a “desired” function $S_d(s)$ by inputting the numerator and the denominator coefficient vectors. Then, you can use S_d to construct `Sdesired` as evaluations of S at the frequencies `theta`.
3. Use previously designed S: If you have a sensitivity function S at hand, you can use it to construct `Sdesired` as evaluations of S at the frequencies `theta`.
4. Give manually: You can type the vectors `Sdesired` and `theta` directly.
5. Give manually in region: You can change a part of the vectors `Sdesired` and `theta`. The part is specified by the lowest and the highest frequencies, and you can specify
 - the magnitude (dB) and the phase (degree) of `Sdesired`
 - the magnitude of `weight`at points between those frequencies.
6. Give manually by window: You can change a part of the vectors `Sdesired` and `theta`, by specifying
 - center frequency and width of the window
 - new magnitude (dB) and new phase (degree) and weight at the center.Then, it automatically modify the curves in the window with exponential functions.
7. Give Interactively in Plot: You can modify the magnitude (dB) and the phase (degree) of `Sdesired`, and the magnitude of `weight`, by left-clicking on a figure. If you right-click, then the modification will be finished. The clicked point and the points around that point will be modified with exponential functions automatically.
8. Keep current: `Sdesired` and `weight` are unchanged.

1.5 Other Design Parameters

You can modify

- `gamma`: the uniform bound of the sensitivity gain
- `xspec`: fixing magnitude and phase in the Bode plot

```
-----  
                Other Design Parameters  
1. Change upper modulus bound of S  
2. Change additional specified values  
3. Return to Input Data Menu  
-----
```

Enter choice (3):

1.5.1 Changing `gamma`

To modify `gamma`, input a positive number (Here, the unit of the number is *not* dB.)

1.5.2 Changing `xspec`

There are four parameters for `xspec`:

- `xspec.freq`: frequency of a fixed point
- `xspec.mag`: fixed magnitude (dB) at `xspec.freq`
- `xspec.phase`: fixed phase (degree) at `xspec.freq`
- `xspec.sharpness`: how strong to fix magnitude and phase (Set to one if you want to *definitely-fix* it.)

There are several ways to add/modify `xspec`, with the following menu:

```
-----  
                Additional Specifications  
1. Modify one specification  
2. Add specification manually  
3. Add specification from current S  
4. Add specification in plot  
5. Remove specifications  
6. Return to Other Design Parameters  
-----
```

Enter choice (6):

1. **Modify one specification:** You can modify the current `xspec` manually.
2. **Add specification manually:** You can add a fixing point by specifying manually the frequency (rad/sec), the magnitude (dB), the phase (degree) and the sharpness.
3. **Add specification from current S:** You can add a fixing point by extracting the magnitude (dB) and the phase (degree) at the frequency (rad/sec) you specify.
4. **Add specification in plot:** You can add a fixing point by clicking the magnitude (dB) and the phase (degree) on the Bode plot. The frequency is chosen at the mean of the two clicks (gain-click and phase-click).
5. **Remove specifications:** You can remove some fixing points.
6. **Return to Other Design Parameters:** The parameter `xspec` is unchanged.

2 Design Controller

If you choose 2 in Main Menu, you can design a controller. Before the design, the plant `sysP` and a desired frequency response `theta` and `Sdesired` must be input in the workspace.

First, you need to decide an initial point for optimization. This is done with the menu:

```
-----
                Initialization of NLSsolver
1. Latest solution
2. Approximate peak solution
3. Spectral zeros
4. Maximum entropy solution
-----
Enter choice (1):
For beginners, we suggest to use "2.Approximate peak solution".
Next, you choose an option:
```

```
-----
                Optimization Options
1. Choose a particular routine
2. Run all available routines
3. Run all and use the best routine
4. Compare computational performance
-----
Enter choice (1):
For beginners, just choose 1.Choose a particular routine".
```

Finally, you can choose an algorithm for solving an optimization problem. There are four algorithms available:

```
-----
                Design Controller
1. Method 1 (Levenberg-Marquardt)
2. Method 2 (Gauss-Newton)
3. Method 3 (Levenberg-Marquardt) direct
4. Method 4 (Gauss-Newton) direct
-----
Enter choice (1):
```

If you choose one algorithm, the optimization process will be displayed:

```
                Modified Levenberg-Marquardt Iterations
Iteration  Functional      Delta      Norm of step
    1         3.6394         2          1
    2         3.6394         1         1.0585
    3         3.6394         0.5         1
    4         3.6394         0.25        0.5
    5         0.91218        0.5         0.25
    6         0.12019         1          0.5
    7         0.0013377        2          0.30726
    8         1.4386e-007        4          0.016384
    9         4.0578e-014        8          0.00033302
   10         1.0639e-020        16         7.7536e-008
Modified Levenberg-Marquardt was successful
*****
Gradient norm: 6.9535e-012
Maximal modulus of spectral zeros: 0.81113
*****
```

You have successfully designed a controller
Press any key to continue

To see the designed controller and sensitivity function, go to "4.Plot Menu" in Main Menu.

3 Load Controller for Comparison

If you choose 3 in Main Menu, you can load a controller for comparison. The controller should be named `sysCmanual` and saved as `tf`-format in a `mat`-file. The `mat`-file should be located at the current directory or one level upper/lower directory.

4 Plot Menu

If you choose 4 in Main Menu, you will see the current controller `sysC` and the current sensitivity function `sysS`, as well as Plot Menu as follows:

Designed controller:

Transfer function:

$0.2951 s^3 + 0.2106 s^2 + 8.233 s + 0.005483$

 $s^4 + 21.71 s^3 + 210.2 s^2 + 1021 s + 1935$

Corresponding sensitivity function:

Transfer function:

$s^4 + 16.8 s^3 + 127.7 s^2 + 394.3 s$

 $s^4 + 16.8 s^3 + 127.7 s^2 + 393.9 s + 2.114$

Plot Menu
1. Plot Bode of S
2. Plot Bode of T
3. Plot Bode of CS
4. Plot Bode of PS
5. Plot Bode of PC
6. Plot Bode of Plant
7. Plot Bode of Controller
8. Plot Weight
9. Plot Step Response
10. Plot Control Input for Step Response
11. Change Plot Options
12. Return to Main Menu

Enter choice (12):

By choosing an appropriate number, you can plot a figure. If you choose 11, then you will specify the following parameters for plot:

Give Example Name for Display (Our design):

Give length of step response: ([10])

Gridding on? (n)

Give lower frequency for plotting: ([0.001])

Give upper frequency for plotting: ([1000])

Give font size: ([12])

Give line width: ([1.5])

5 Print Menu

If you choose 5 in Main Menu, the following menu appears:

```
-----  
                Print Menu  
1. Print Specific Plot  
2. Print All Default  
3. Change Printing Parameters  
4. Return to Main Menu  
-----
```

Enter choice (4):

By choosing 1 or 2, you can make eps or jpg files of figures. If you choose 3, you can choose a file name, eps/jpg format, and width/height of the plot.

Give example name (FlexBeam):

Give file type (eps):

Give plot width: ([18])

Give plot height: ([13])

For example, if you print figures with the setting above, then you will get files FlexBeamS.eps, FlexBeamT.eps, etc.

6 Load Design

If you choose 6 in Main Menu, you can load data from mat-files. First, choose the directory in which a mat-file is located, and then choose the mat-file. A mat-file to be loaded should be located at the current directory or one level upper/lower directory.

7 Save Design

If you choose 7 in Main Menu, you can save all the data in the workspace. First, choose the directory in which you would like to locate a mat-file, and then type in a file name (for example, tmp for making tmp.mat.)

8 Display Variables

If you choose 8 in Main Menu, you can see all the variables currently in the workspace:

Currently

Your variables are:

Cintegrators	mainflag	rho	xspec
Creldegree	mainoptions	sharpness	xspectemp
Sdesired	name	spectralzeros	
ans	peakfreq	sysP	
chosenmainoption	plotparameters	theta	
gamma	printparameters	weight	

Which do you want to display (enter returns to main menu)?

If you want to see what the current gamma is, input as

Which do you want to display (enter returns to main menu)? gamma

Then, you will see

```
gamma =  
      2
```

9 Clear Variables

If you choose 9 in Main Menu, the following menu appears:

```
-----  
                Clear Menu  
1. Clear All Variables in the Workspace  
2. Clear Some Variables in the Workspace  
3. Return to Main Menu  
-----
```

Enter choice (3):

- If you want to clear all the variables in the workspace, choose 1.
- If you want to clear some variables, choose 2. Then, you will see all the variables in the workspace, and will be asked as:

Currently

Your variables are:

Cintegrators	clearflag	name	sysP
Creldegree	clearoptions	peakfreq	theta
Sdesired	closeflag	plotparameters	weight
ans	closeoptions	printparameters	xspec
chosenclearoption	gamma	rho	xspectemp
chosencloseoption	mainflag	sharpness	
chosenmainoption	mainoptions	spectralzeros	

Which do you want to clear?

Input one variable name you want to clear. You can clear several variables by repeating this.

10 Close Figures

If you choose 10 in Main Menu, the following menu appears:

```
-----  
                Close Figure Menu  
1. Close All Figures  
2. Close A Figure  
3. Return to Main Menu  
-----
```

Enter choice (3):

- If you want to close all the figures, choose 1.
- If you want to close one figure, choose 2. Then, you will be asked:

Which figure do you want to close?

Input the number of the figure you want to close.

11 Exit

If you choose 11 in Main Menu, you exit the program Sshaper. All the variables are kept in the workspace, and also saved automatically in DesignMatFiles/DataLatest.mat.

A Variables

- Systems

`sysP` : Plant transfer function. **tf**-format.
`sysC` : Controller transfer function. **tf**-format.
`sysS` : Sensitivity function. **tf**-format.
`sysCmanual` : Controller for comparison.

- Design parameters

`Sdesired` : Complex vector for a desired frequency response.
`theta` : Real vector of frequencies for `Sdesired`.
`weight` : Vector of positive numbers for the weight.
`gamma` : Uniform bound of S . $\|S\|_\infty < \gamma$.
`xspec` : Additional conditions
`xspec.freq`: frequency
`xspec.mag`: gain (dB)
`xspec.phase` : phase (degree)
`xspec.sharpness`: closeness to the frequency axis of the condition