When the adaptation of SM controllers is needed?

April 29, 2014

Chattering

Consider the first order system

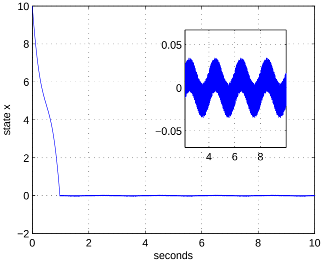
$$\dot{s} = f(s, s^T) + g(s, s^T)(u + \phi(t))$$

$f(s, s^T), g(s, s^T)$ are known functions and $|\phi(t)| < L$ is an unknown perturbation bounded by a constant L

The control is given by

$$u = -ksign(s)$$

where the constant $k > L$.



Chattering

The chattering effect is one of the main disadvantages of sliding mode control. To reduce the chattering effect on the system:

- Increase the order of the controller, adapt the controller gain. For example, replace relay controller with super-twisting algorithm.

- Identify the perturbation and use the result as a SMC gain.

Chattering

- Recently two important approaches to SM adaptation were published.
  - When the upper bound of perturbations and their derivatives are known.
    - Adaptation of the gain to the filtered value of the equivalent control.[Utkin, Poznyak 2013].
    - HOSM based, theoretically exact compensation of uncertainties. [Ferreira, et. al. 2011].
  - When the upper bound of perturbations and their derivatives are unknown. [Shtessel, et. al. 2012] [Bartolini, et. al. 2013].

The upper bound of perturbations and their derivatives are unknown

- Case 1: [Utkin, Poznyak, 2013]
  - The control signal is filtered to estimate the equivalent control.
  - The adaptive gain follows the equivalent control.
  - The adaptive gain is set to be greater than the magnitude of the perturbation in a desired proportion.

The upper bound of perturbations and their derivatives are known

Advantages

- An ideal-sliding mode is achieved.
- The perturbation can be compensated, theoretically, exactly.
- The controller gain depends on the magnitude of the perturbation.

The upper bound of perturbations and their derivatives are known

Disadvantages

- In application the estimation of the equivalent control is delayed, thus SM may be lost.
- Filter time constant is needed.

The upper bound of perturbations and their derivatives are known

- Case 2: A HOSM differentiator is used to estimate the perturbation [Ferreira, et. al. 2011].
  - The estimated signal is used to directly compensate the perturbation.
  - The estimated signal can also be used as a SM control gain.

The upper bound of perturbations and their derivatives are known

Advantages

- The perturbation can be compensated, theoretically, exactly.
- The controller gain depends on the magnitude of the perturbation.
- The control signal is smooth, because it is possible to use only nominal control.

The upper bound of perturbations and their derivatives are known

Disadvantages

- With some noise in the input, the observer has an estimation error that may cause the loss of precision.
- When the actuator time constant is more than observer precision and less than identification precision, it is reasonable the usage of uncertainties identification as a SM gain .

The upper bound of perturbations and their derivatives are unknown

- Case 1: Adaptation based on an energy function [Shtessel, et. al. 2012]
  - The control gain is increased until SM is established.
  - Once the SM is established, the gain is decreased until an energy function reach a pre-established value.
  - The trajectories of the system stays in a level curve of the energy function.

The upper bound of perturbations and their derivatives are unknown

Advantage

- The bound of the perturbations is not required to be known.

The upper bound of perturbations and their derivatives are unknown

Disadvantage

- Only a real-sliding mode is achieved.

The upper bound of perturbations and their derivatives are unknown

- Case 2: Adaptation based on the lost of SM [Bartolini, et. al. 2013]
  - Increase the controller gain until the (approximate) 1-sliding mode is detected.
  - The gain is gradually reduced until the sliding mode is lost due to an insufficient control magnitude.
  - The controller gain is increased in one impulse to provide for the immediate convergence restoration.
  - Then it is decreased gradually until the approximate 1-sliding mode is once more lost.

The upper bound of perturbations and their derivatives are unknown

Advantage

- The bound of the perturbations is not required to be known.

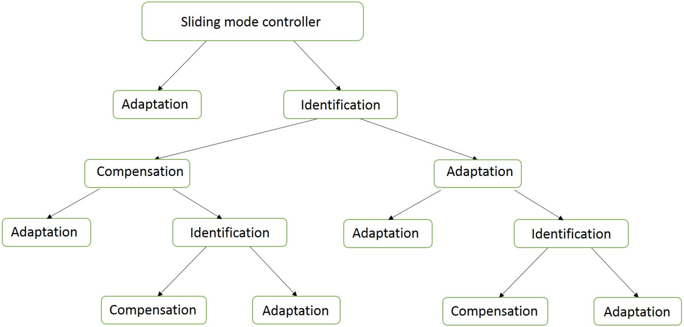
The upper bound of perturbations and their derivatives are unknown

Disadvantage

- Only a real-sliding mode is achieved.

Adaptation procedure

The following process is suggested to adapt the SMC gain.



Discussion

- Adapt the control gains or reconstruct the perturbation and compensate?
- Does the adaptation make sense in systems with known bounds of the perturbations?
- Adaptation in systems with unknown bounds of the perturbations:
  - gain overestimation?
  - How to guarantee the ability to retain the sliding mode with minimal gains?
  - The best concepts for the adaptation algorithms?
  - Lyapunov approach versus the “minoring-majoring” and other techniques?