- Satellite Attitude Control System Design Using Reaction Wheels

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Outline

1. Overview of Attitude Determination and Control system
2. Problem formulation
3. Control schemes
   3.1 Modified PI Controller
   3.2 Active Disturbance Rejection Control
4. Conclusion

ADCS

- ADCS: Attitude Determination and Control subsystem

- Attitude Determination - Using sensors

- Attitude Control - Using actuators

Disturbance torques

- Aerodynamic
- Gravity gradient
- Magnetic
- Solar radiation
- Micrometeorites

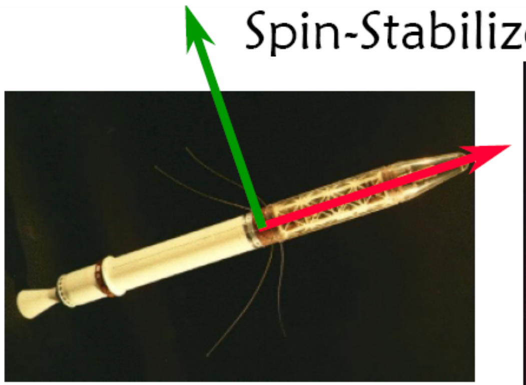
Attitude control modes

- Orbit insertion
- Acquisition
- Slew
- Contingency or Safe

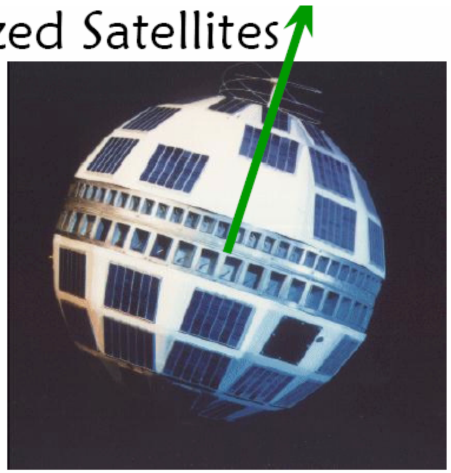
Spacecraft control type

- Passive control
  - Gravity gradient control
  - Spin control

Spin-Stabilized Satellites

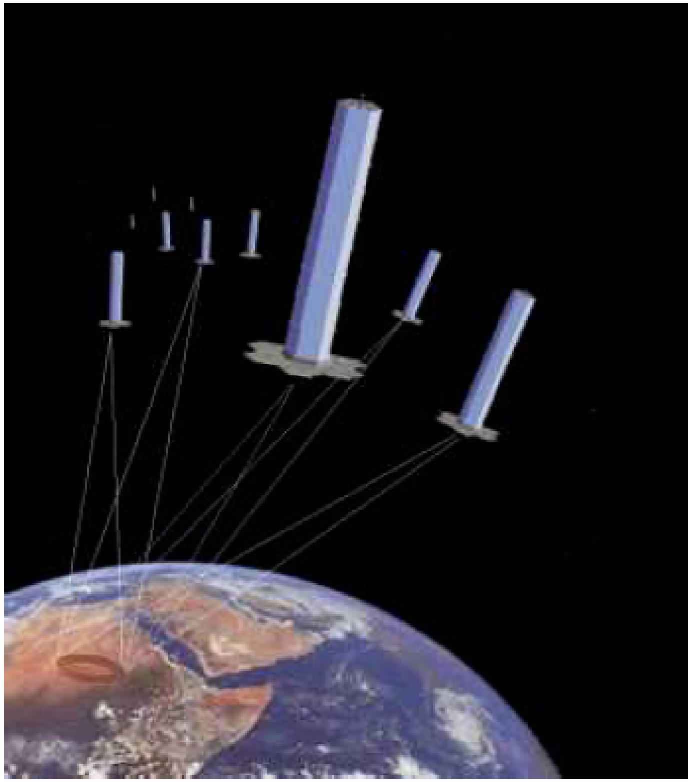


Explorer I (1958) was supposed to be spin-stabilized about its minor axis. It went into a flat spin due to energy dissipation.



Telstar I (1962) was spin-stabilized about its major axis, spinning at about 200 RPM.

Gravity-Gradient Stabilization



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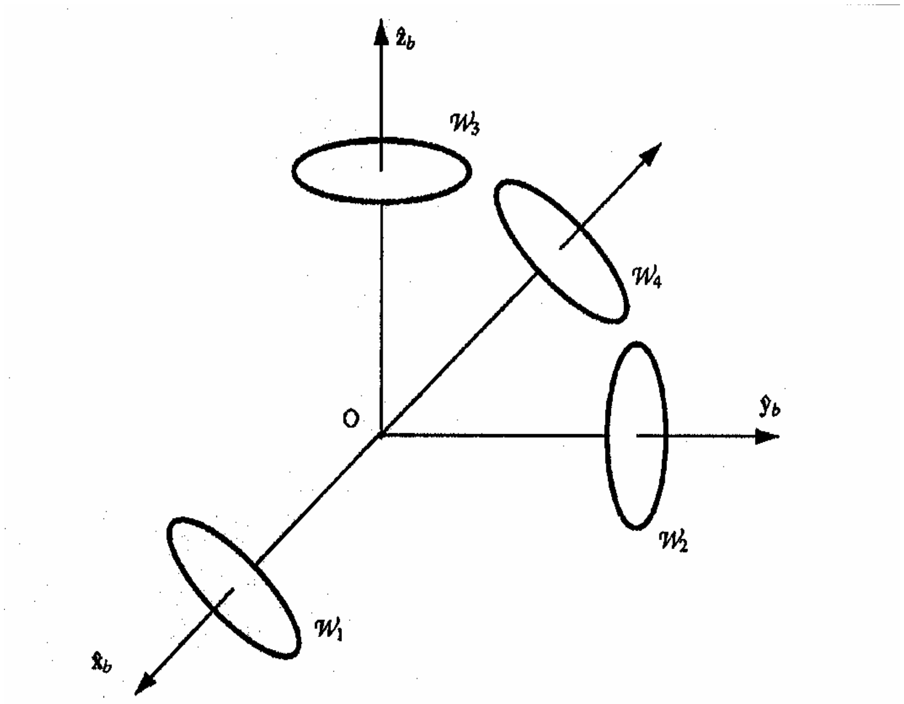
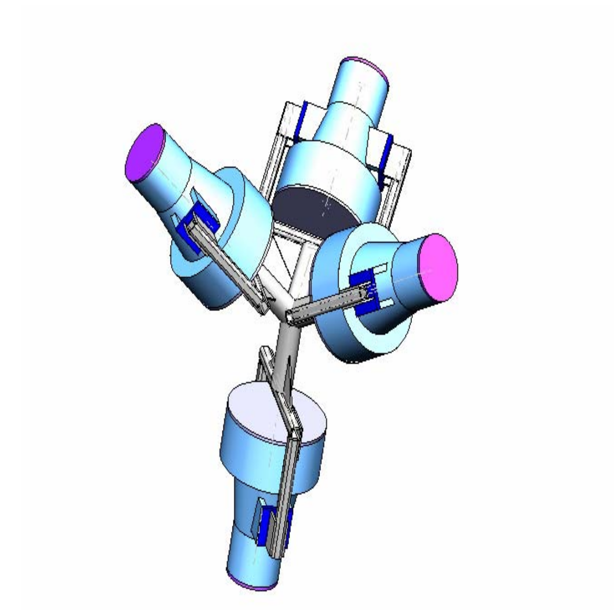
Spacecraft control type

- Active control (Actuators)
  - Reaction wheels
  - Momentum wheels
  - Control - moment gyros
  - Magnetic torquers
  - Gas Jets or Thrusters

Tetrahedron configuration of Reaction wheels



Configuration of energy/momentum wheels.



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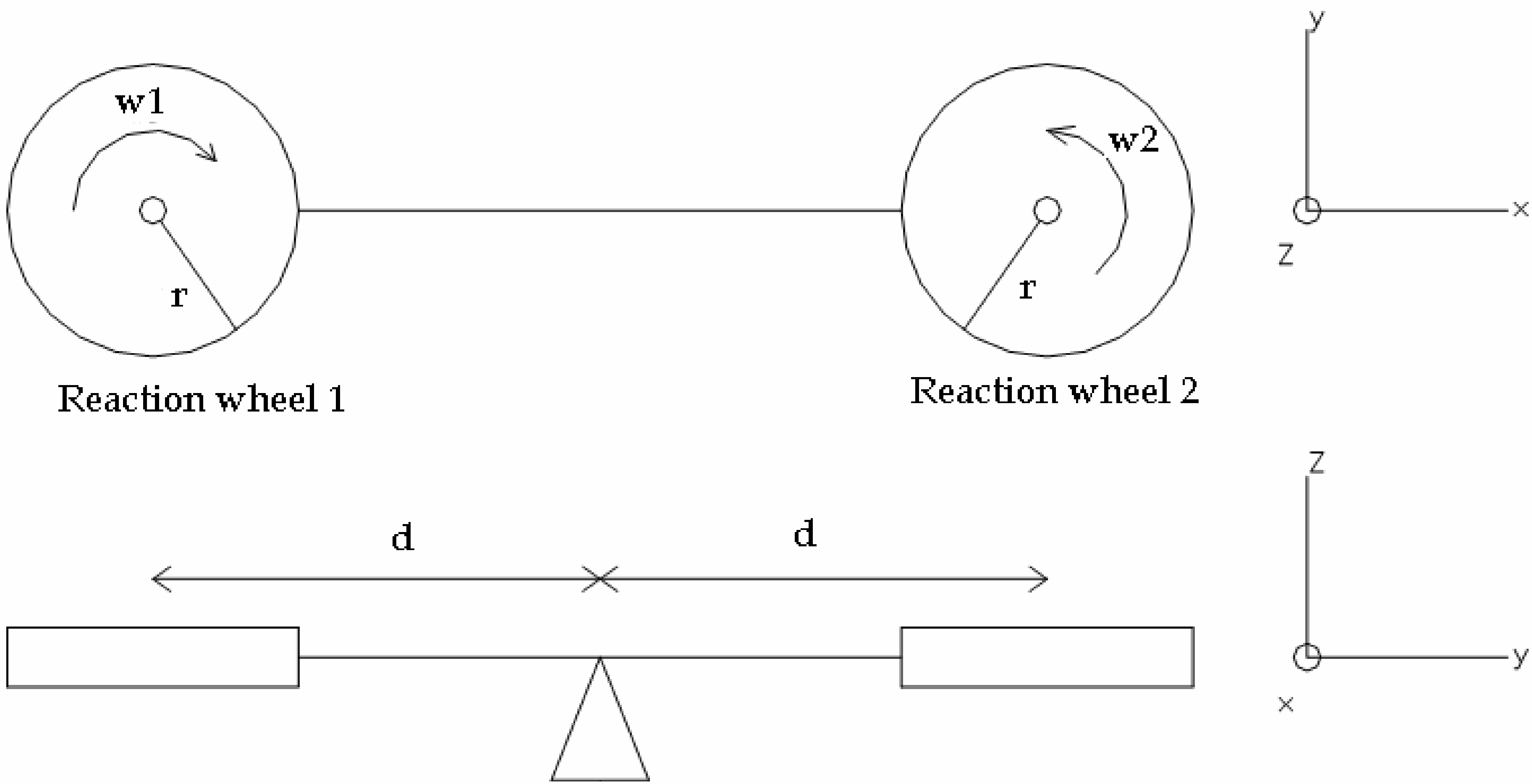
Problem formulation



Mathematical model

Angular momentum of each disk

$$H_1 = I_1 w_1 = \left[\frac{1}{2} m r^2 + m d^2\right] \left[-w_1\right]$$

$$H_2 = I_2 w_2 = \left[\frac{1}{2} m r^2 + m d^2\right] \left[w_2\right]$$

M = Mass of the space craft

m_i = mass of the reaction wheel

w_i= angular velocity of the wheel

θ = Angular position of space craft

r = radius of the wheel

I= moment of inertia

Moment with respect to the space craft

$$I\ddot{\theta} = \left(Mr^2 + 2Md^2\right)\ddot{\theta}$$

Mathematical model

Conservation of angular momentum

$$\frac{d}{dt}\left[H_1 + H_2\right] = I\ddot{\theta}$$

$$\frac{d}{dt}\left[\left(\frac{1}{2}mr^2 + md^2\right)(-w_1) + \left(\frac{1}{2}mr^2 + md^2\right)(w_2)\right] = \left(Mr^2 + 2Md^2\right)\ddot{\theta}$$

$$\frac{d}{dt}(-w_1 + w_2) = 2.\frac{M}{m}.\ddot{\theta}$$

$$\frac{(-w_1 + w_2)}{2} = \frac{M}{m}\dot{\theta} + c$$

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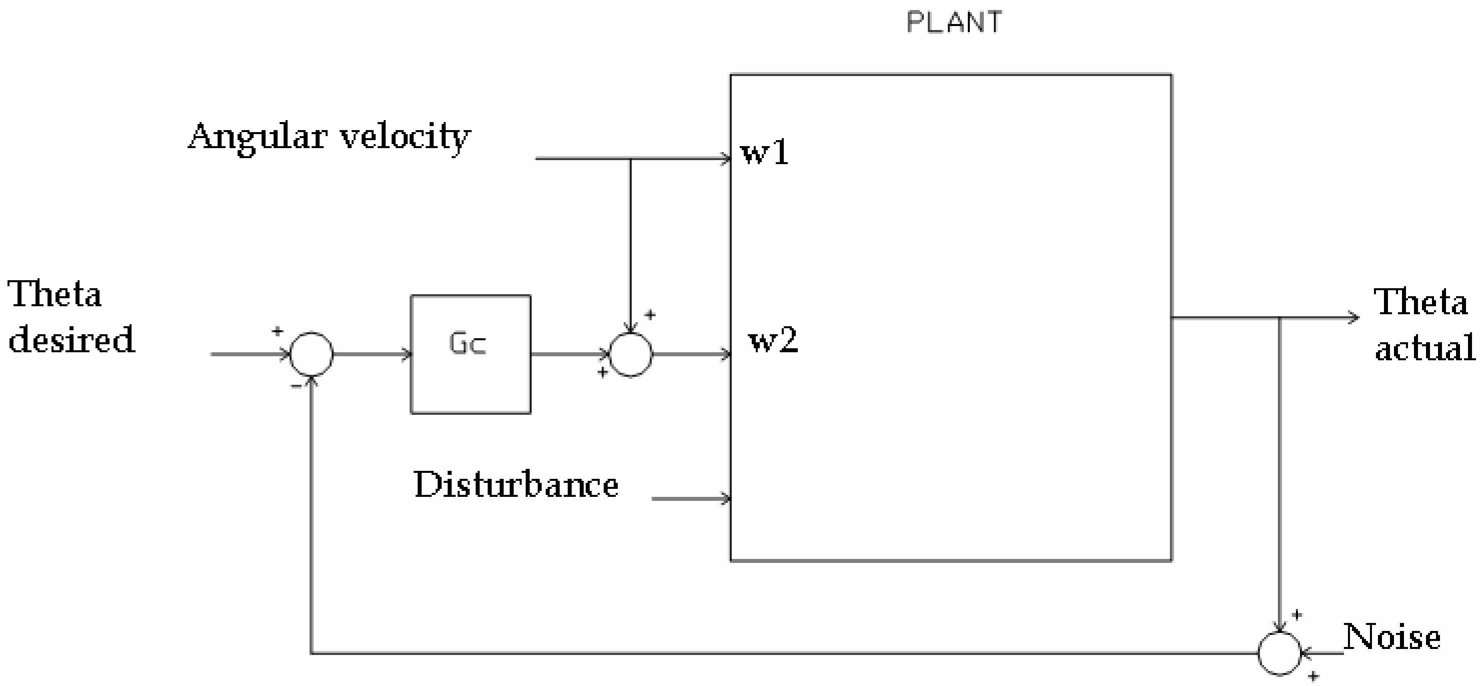
Control Scheme

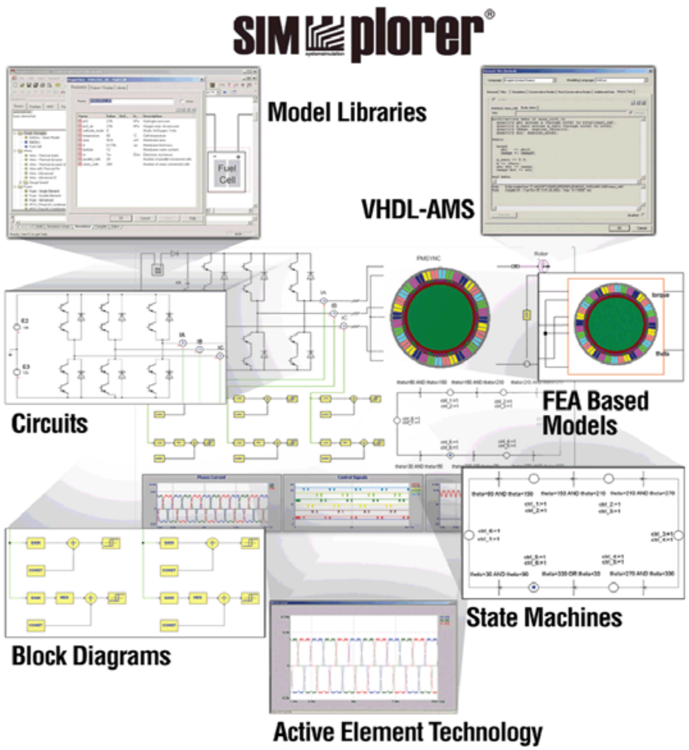


Two types of controllers are investigated

- Modified PI Controller
- Active Disturbance Rejection Controller

Simplorer

- Simplorer
  - Circuit element models
  - Electric machine models
  - Data analysis tools
  - Interfaces with Matlab / Simulink



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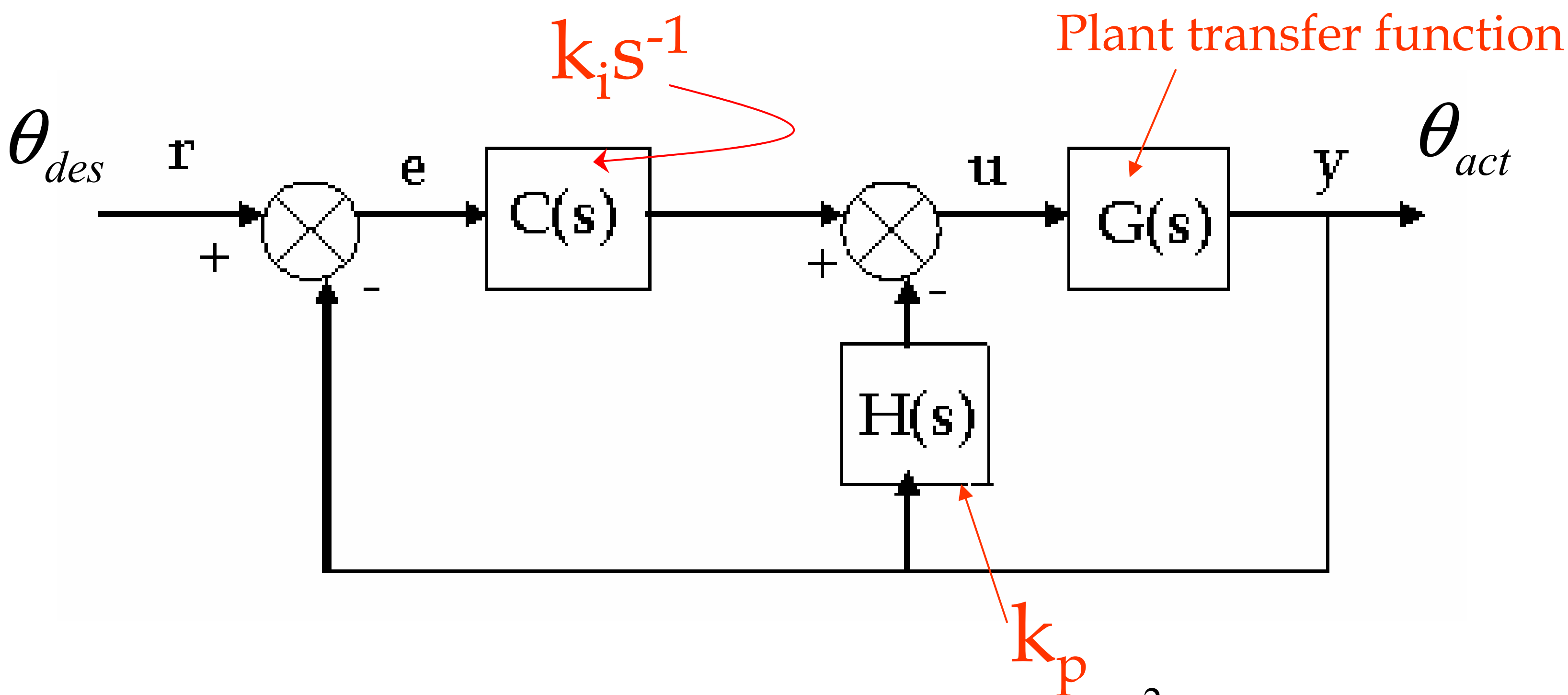
Modified PI Controller

- This controller is used as the baseline controller
- Only one tuning parameter
- Generalized 2 DOF control structure is proposed

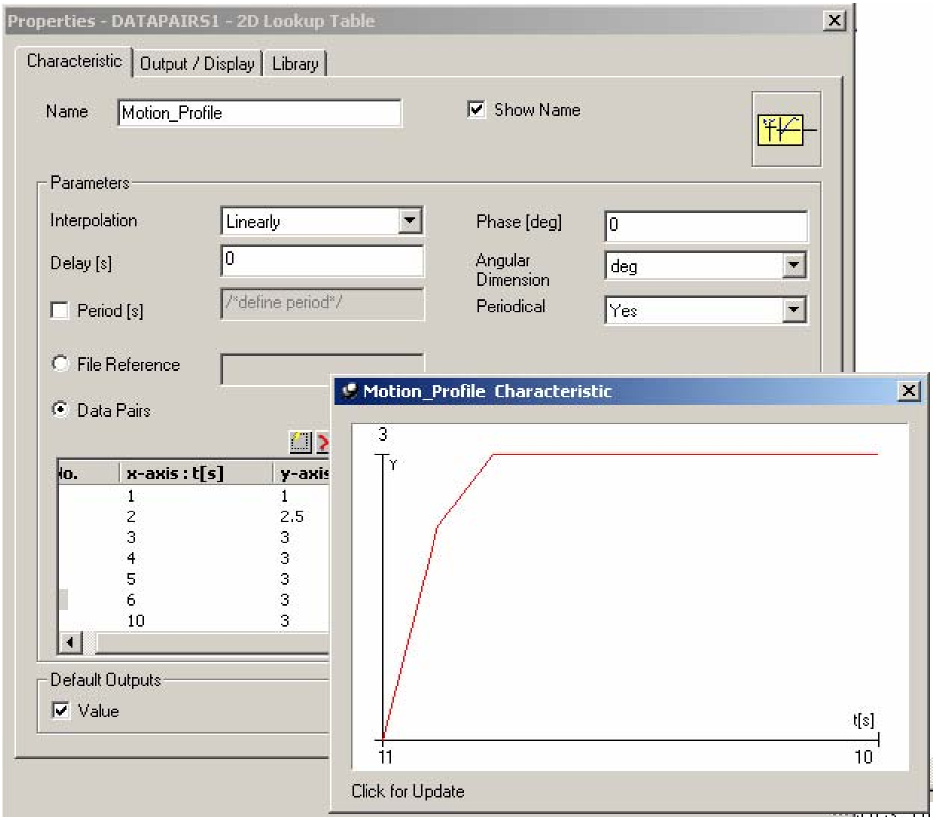
***Reference**: A Robust Two-Degree-of-Freedom Control Design Technique and its Practical Application*
-Robert Miklosovic, Zhiqiang Gao



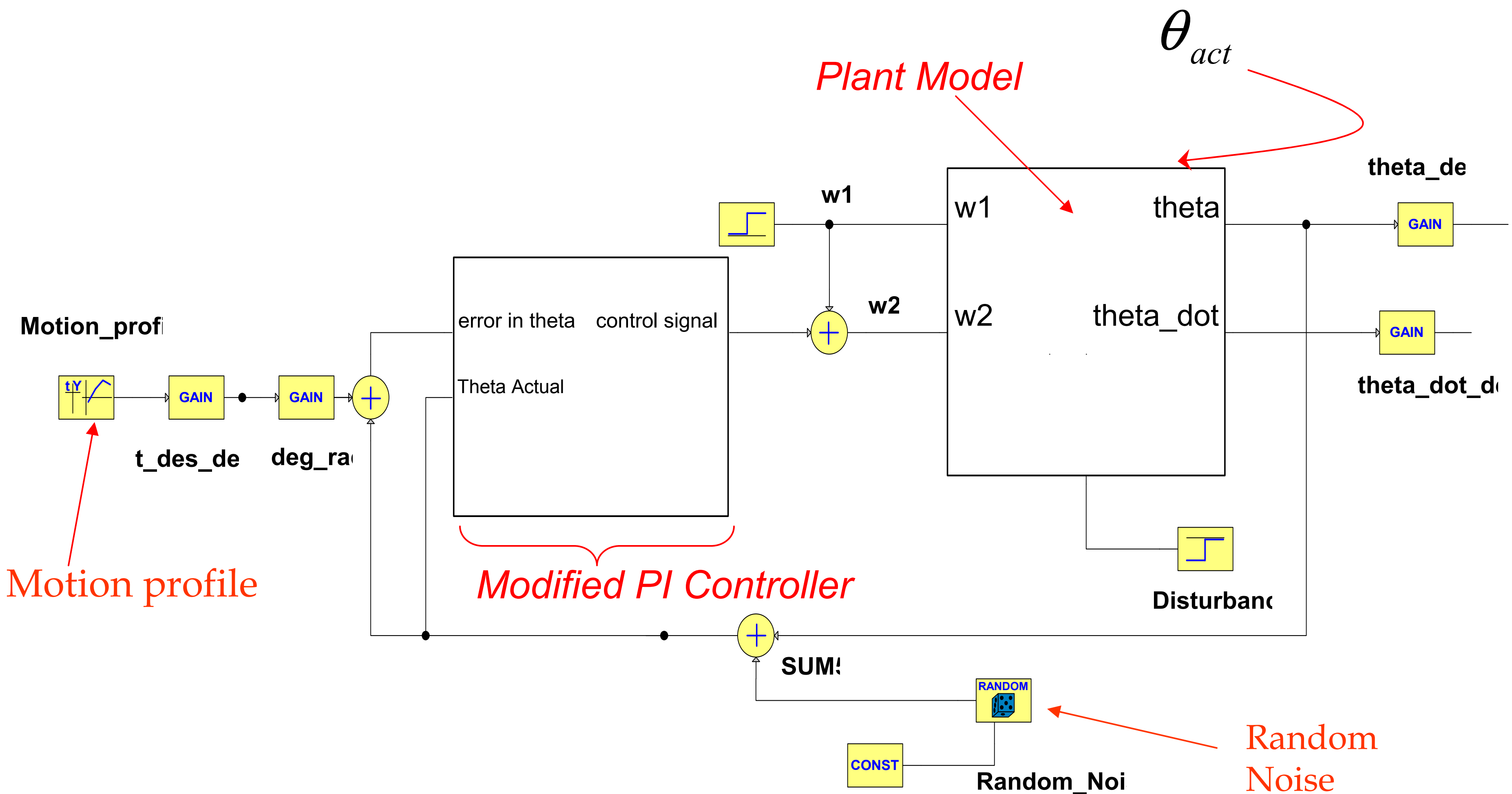
$$(\theta_{des} - \theta_{act}).\frac{k_i}{S} - k_p.\theta_{act} = (\theta_{des} - \theta_{act}).\frac{\omega_c^{\ 2}}{S} - 2.\omega_c.\theta_{act}$$

Motion profiling

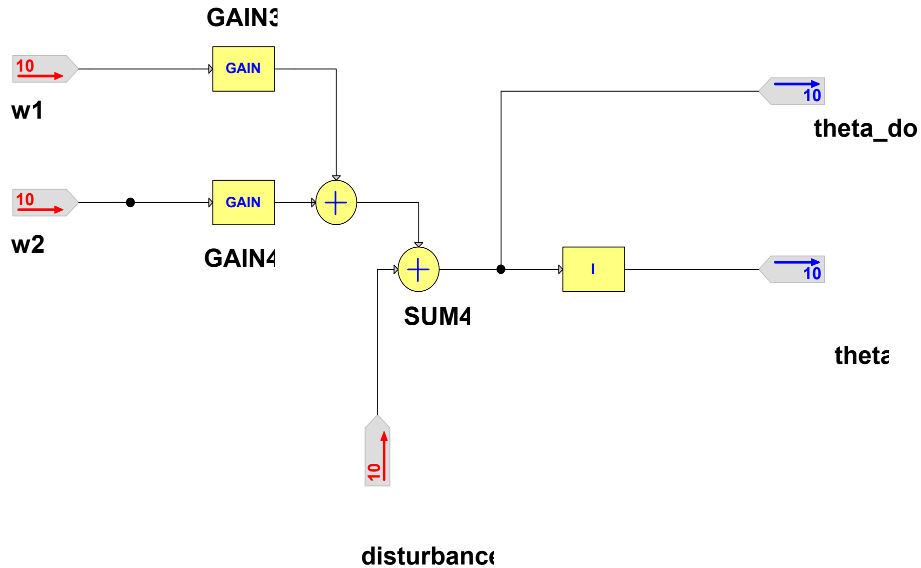
- The desired trajectories as the command input in the closed loop control
- In this case, a profile generator is used to produce desired angle to the system
- Motion profile is used instead of step.



Simulation Results

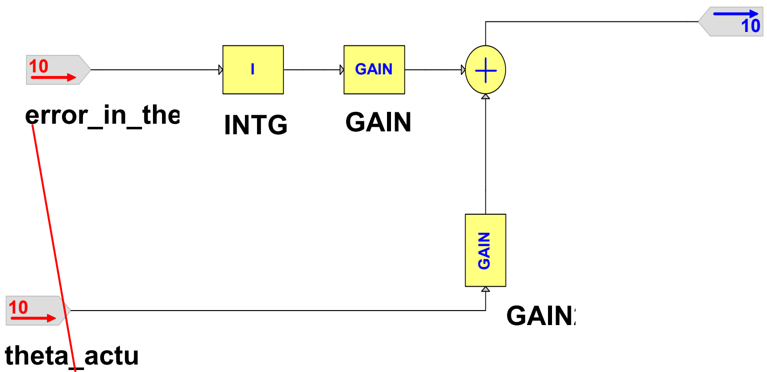


Plant Model



$$\frac{(-w_1 + w_2)}{2} = \dot{\theta} + c$$

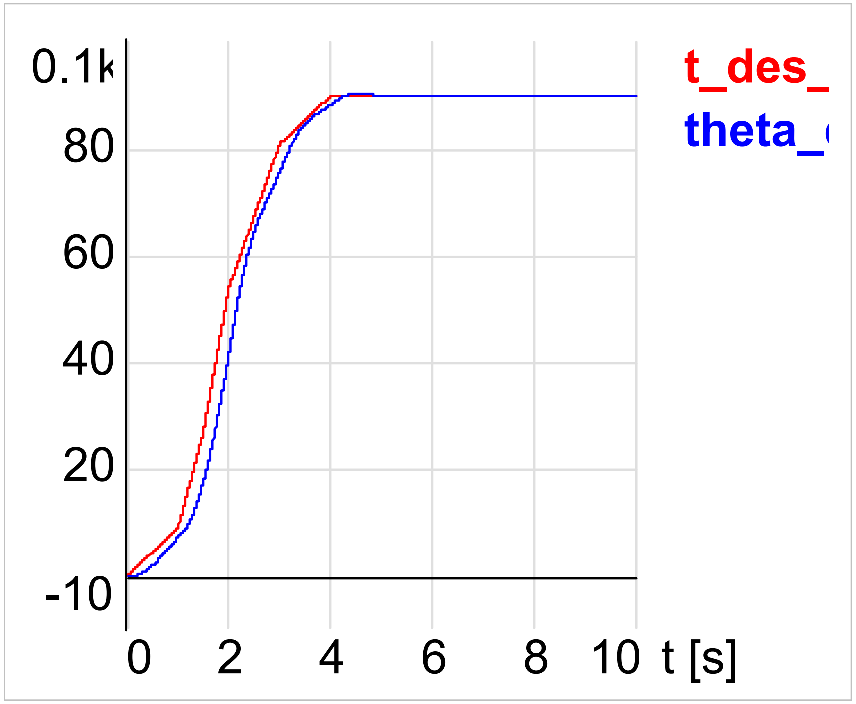
Modified PI Controller

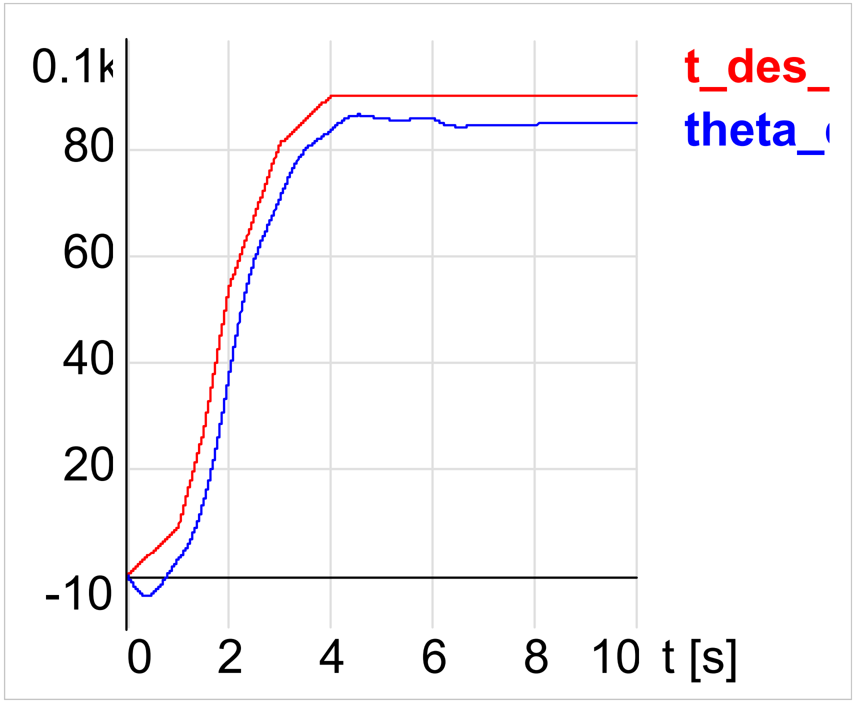


$$(\theta_{des} - \theta_{act}).\frac{k_i}{S} - k_p.\theta_{act} = (\theta_{des} - \theta_{act}).\frac{\omega_c^{\,2}}{S} - 2.\omega_c.\theta_{act}$$

Simulation Results

Theta Actual & desired



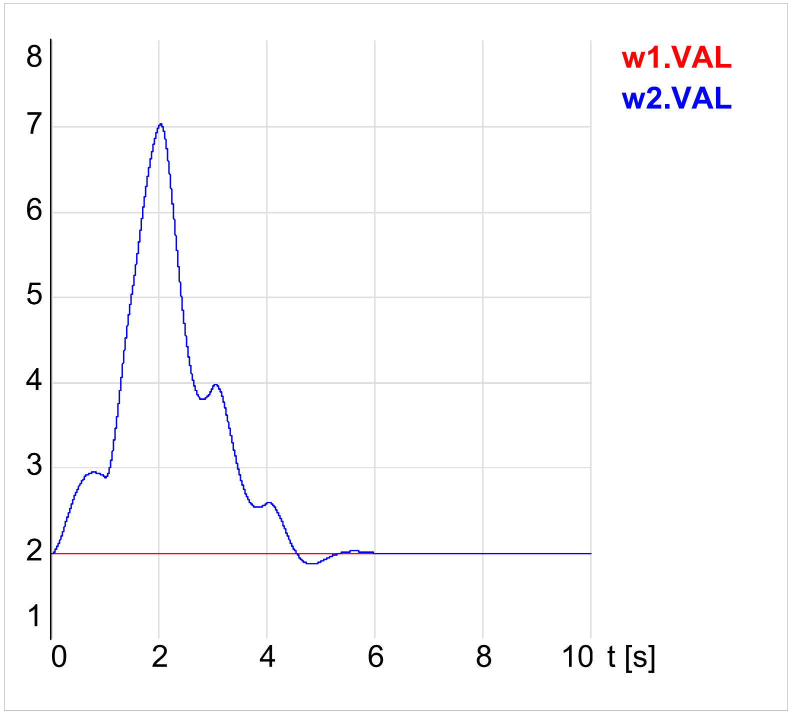


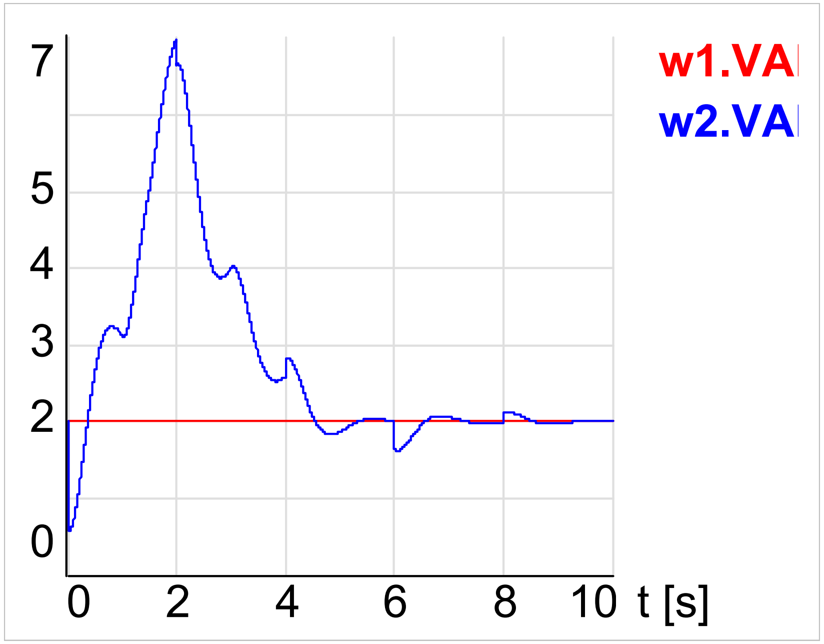
Noise amplitude: 0.07 - 0.1

Noise interval: 2 sec

Simulation Results

control inputs w1 and w2





Noise amplitude: 0.07 - 0.1

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Active Disturbance Rejection Controller

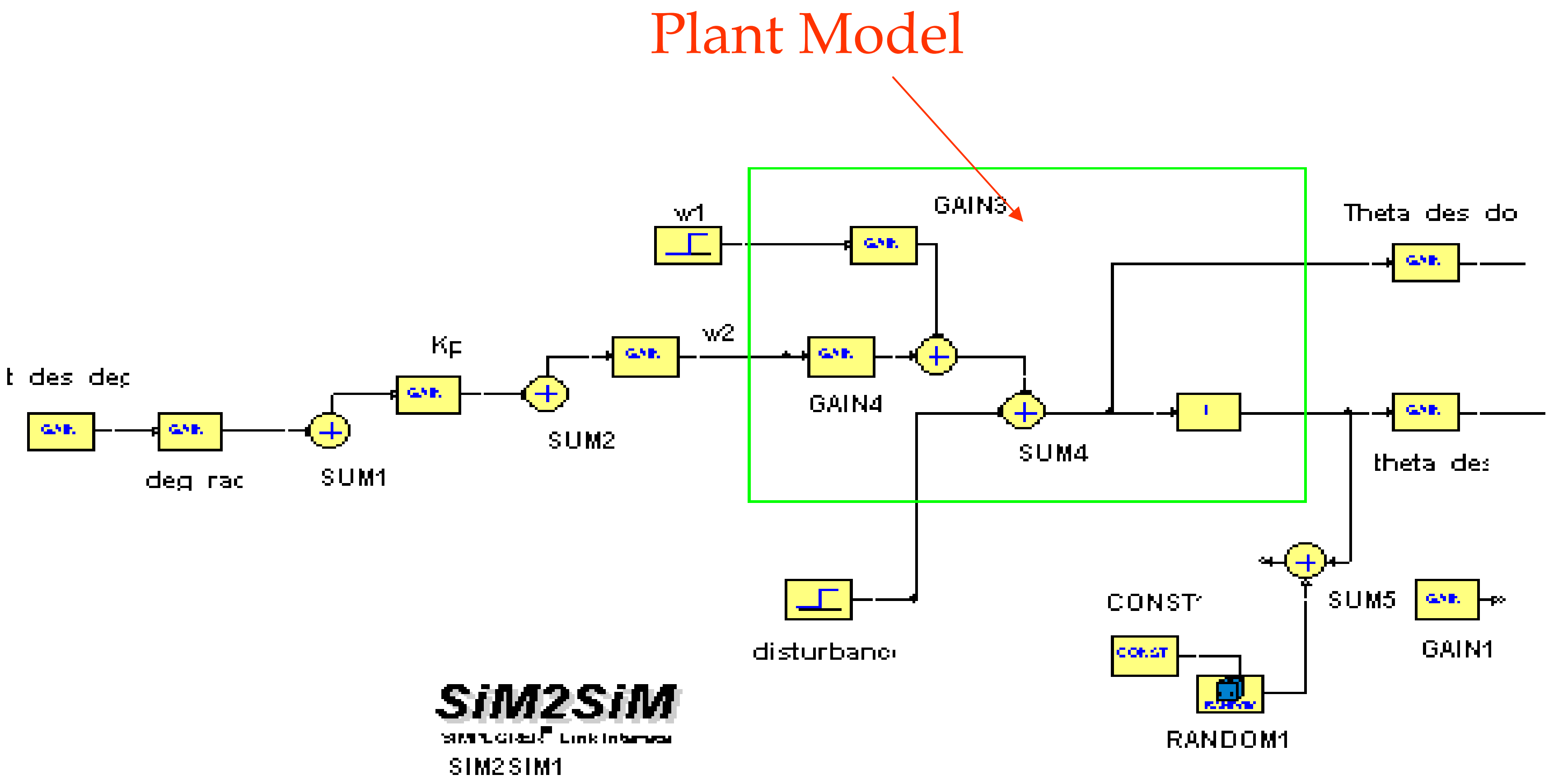
- New digital controller to motion control problems
- Disturbances are estimated using extended state observer (ESO) and compensated in each sampling period.
- Dynamic compensation reduces motion system to a double integrator which can be controlled using a nonlinear PID controller

Extended State Observer

- It is a unique nonlinear observer
- Proper Selection of the gains and functions are critical to the success of the observer
- Once ESO is properly setup, the performance of the observer is quite insensitive to plant variations and disturbances

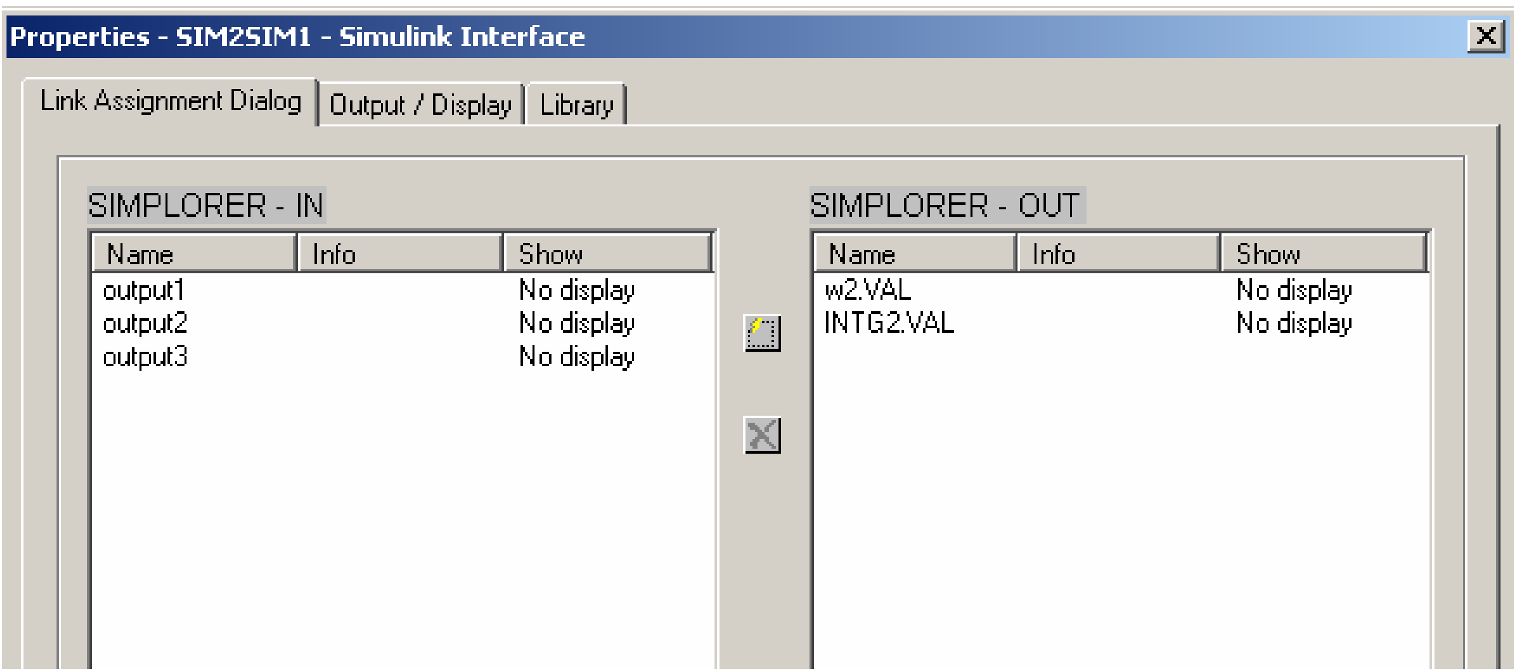
$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} -2\omega_o & 1 \\ -\omega_o^2 & 0 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} b_o & 2\omega_o \\ 0 & \omega_o^2 \end{bmatrix} \begin{bmatrix} u \\ y \end{bmatrix}$$

Simulation Results

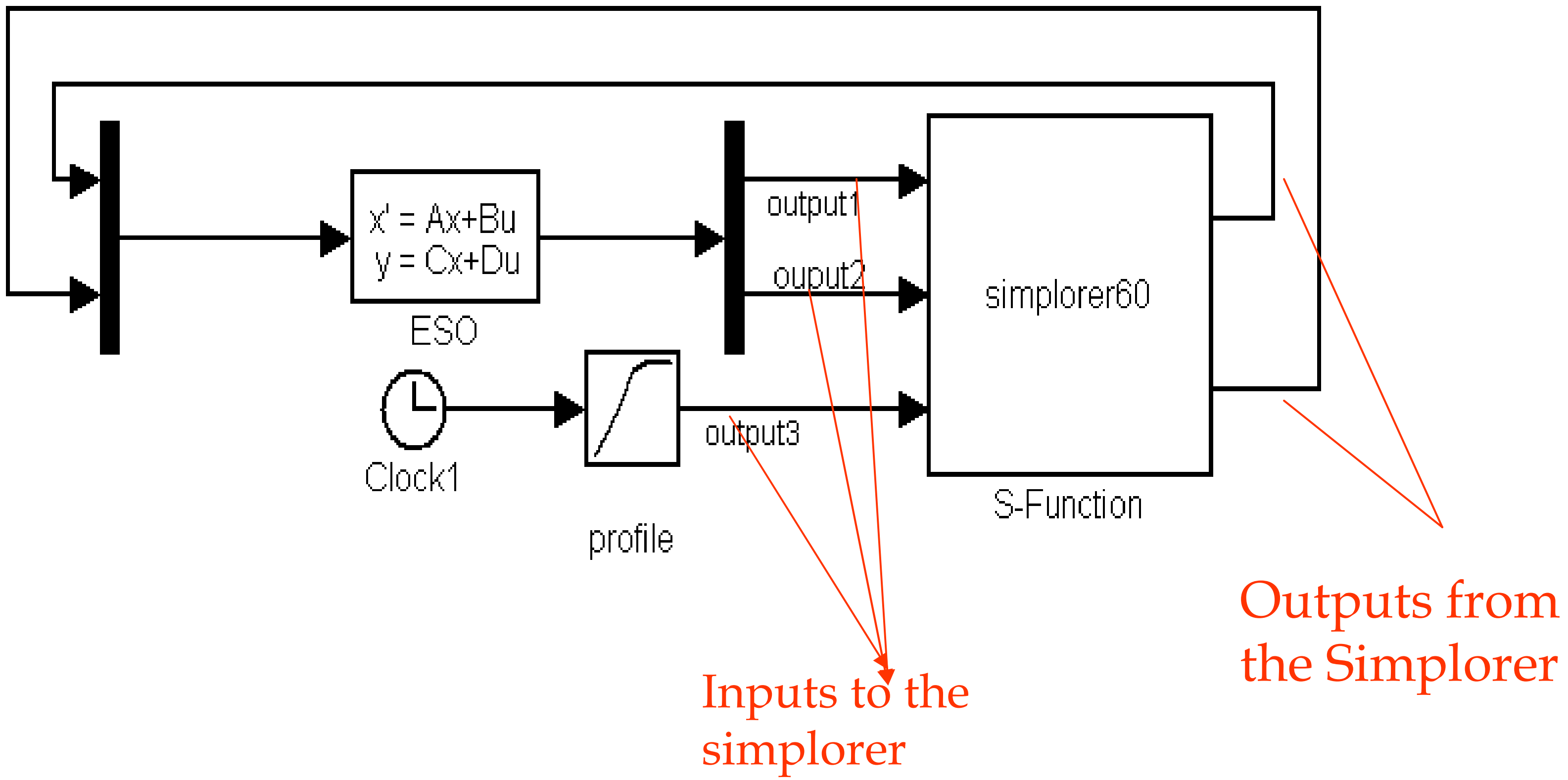


Simplorer and Matlab

Define Simplorer inputs and outputs in the property dialog of the SiM2SiM component

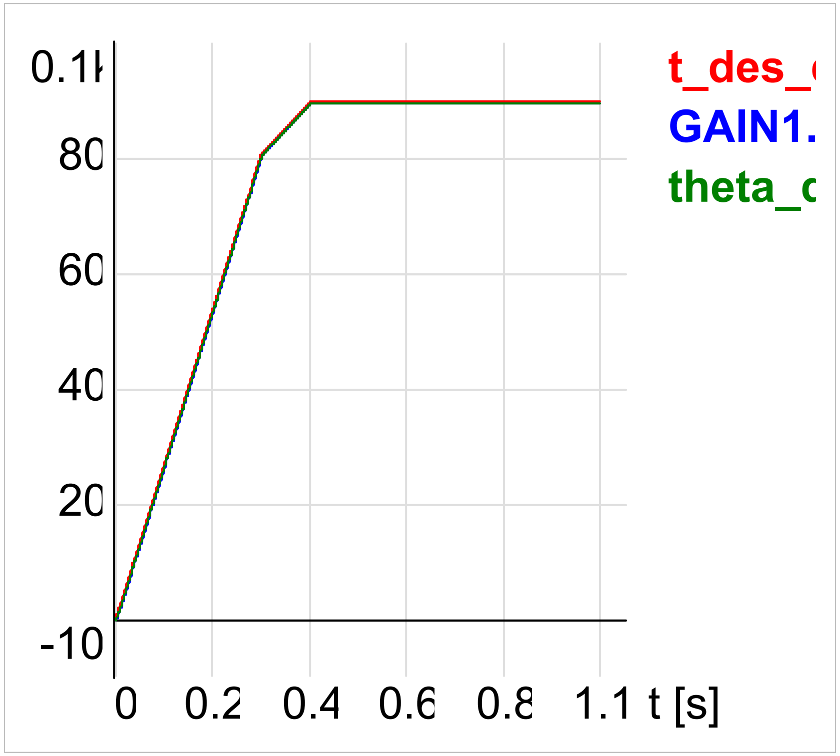


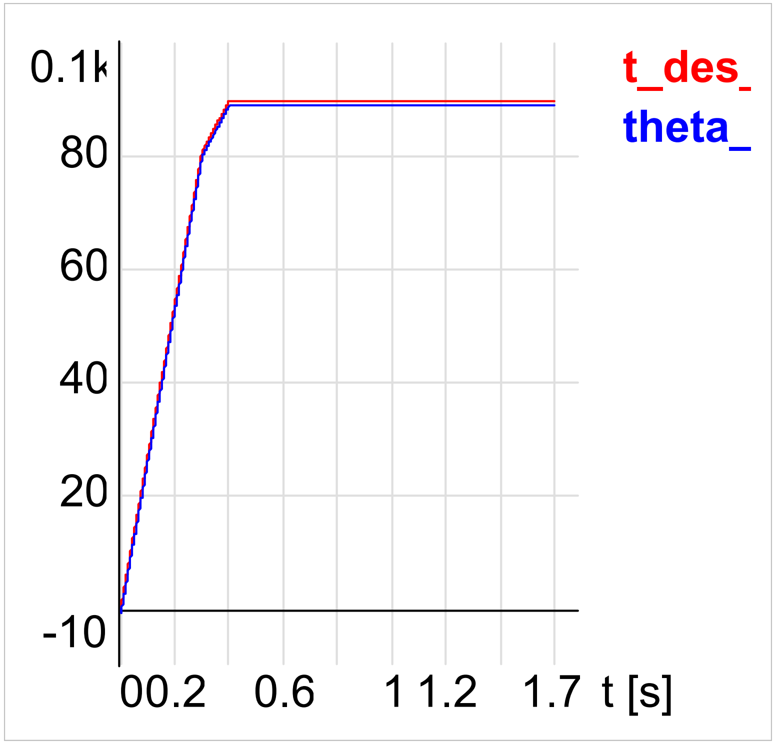
Matlab/Simulink Model



Simulation Results

Theta Actual and Theta desired

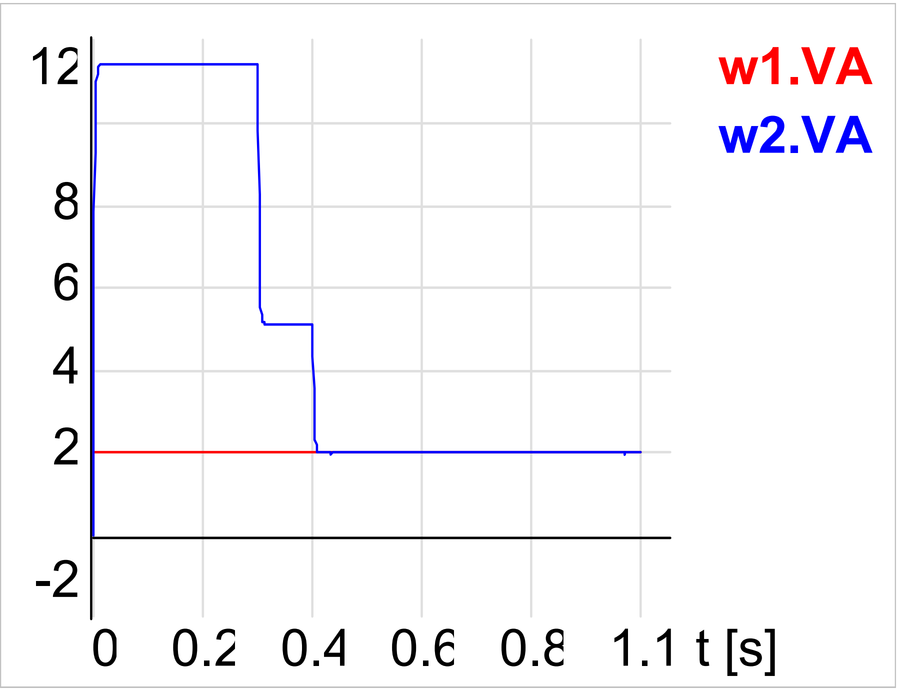


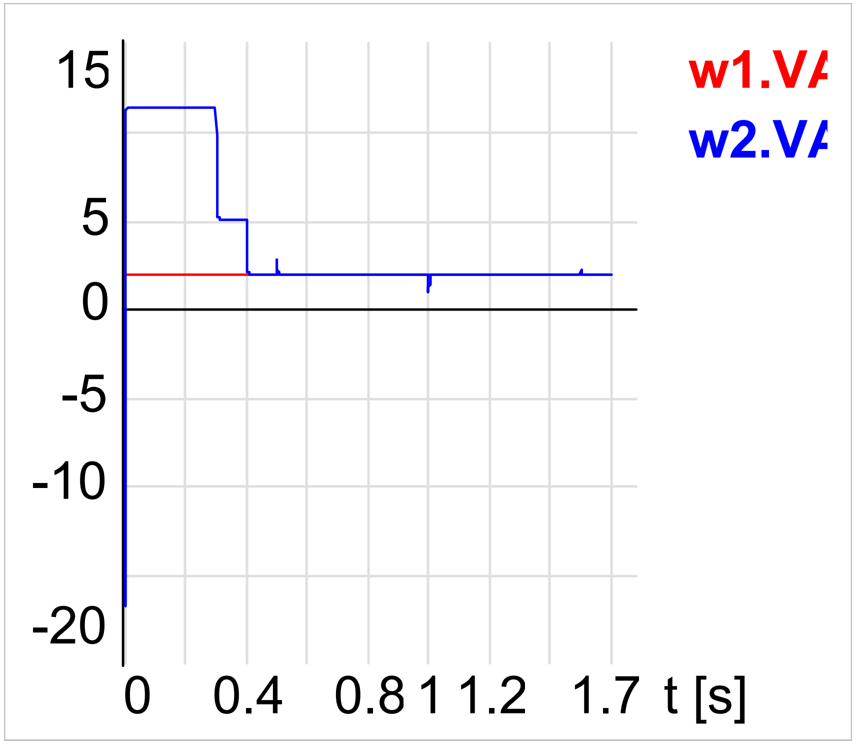


Noise amplitude: 0.05
Noise Interval: 0.5 sec

Simulation Results

w1 and w2





Noise amplitude: 0.05
Noise Interval: 0.5 sec

Conclusion and Future work

- The simulation of Modified PI and ADRC showed that ADRC worked well for the system
- 1 DOF problem will be extended to 3 degrees of freedom problem
- Implementation of the controller design in microcontroller/FPGA microchip.
- Comparisons with other controllers