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Satellite Attitude Control System Design Using Reaction Wheels

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- Satellite Attitude Control System Design Using Reaction Wheels

Bhanu Gouda

Brian Fast

Dan Simon



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



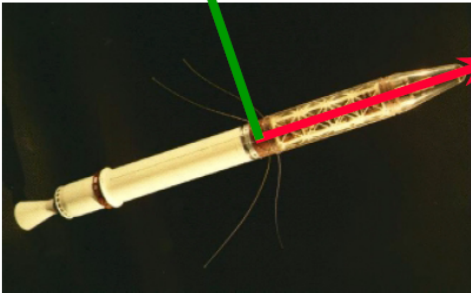
Attitude control modes

- Orbit insertion
- Acquisition
- Slew
- Contingency or Safe

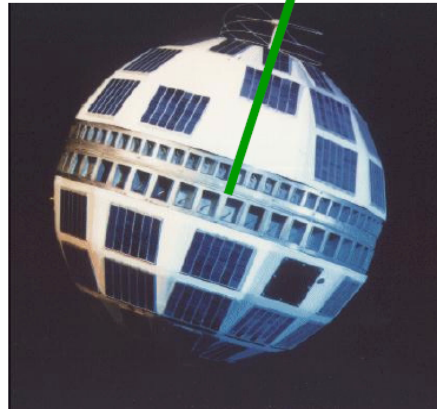
Spacecraft control type

- Passive control
 - Gravity gradient control
 - Spin control

Spin-Stabilized Satellites

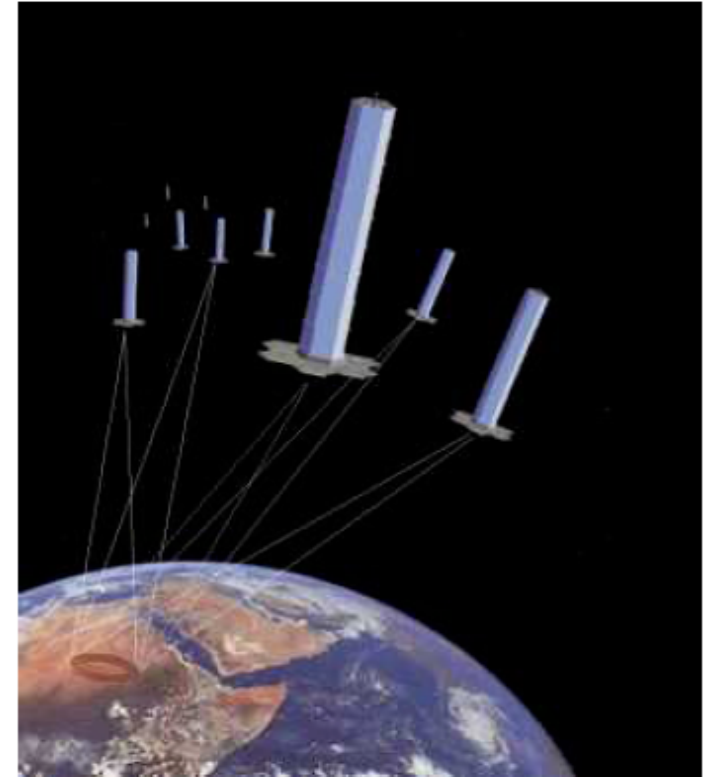


Explorer I (1958) was supposed to be spin-stabilized about its minor axis. It went into a flat spin due to energy dissipation.



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

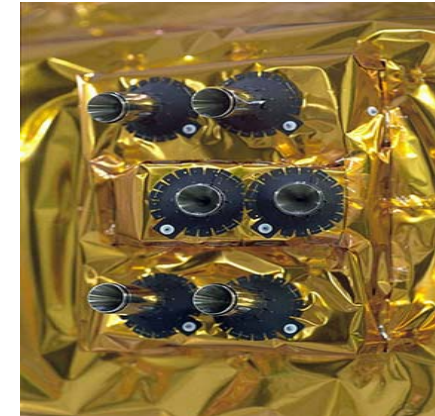
Gravity-Gradient Stabilization



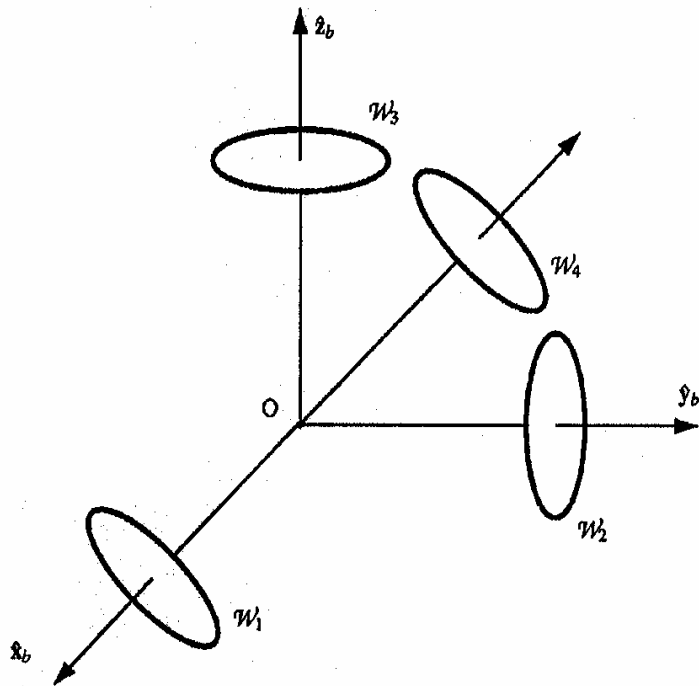
TechSat 21

Spacecraft control type

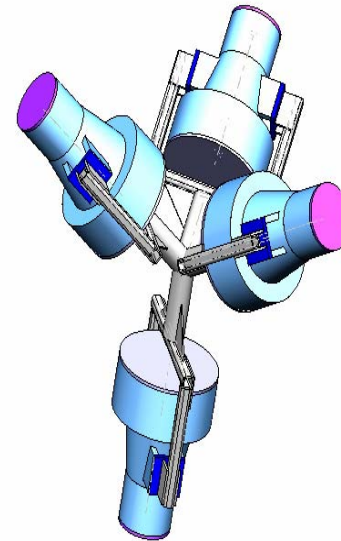
- Active control (Actuators)
 - Reaction wheels
 - Momentum wheels
 - Control - moment gyros
 - Magnetic torquers
 - Gas Jets or Thrusters



Tetrahedron configuration of Reaction wheels



Configuration of energy/momentum wheels.

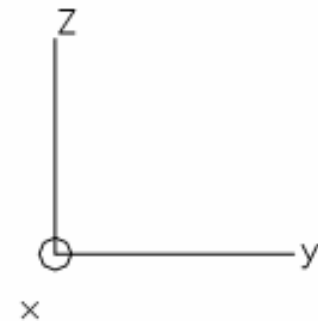
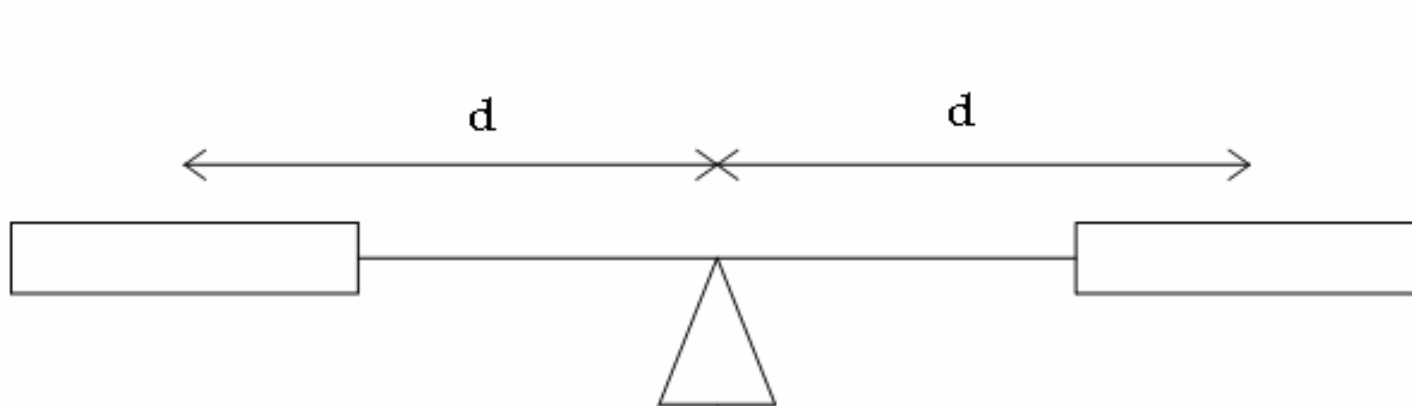
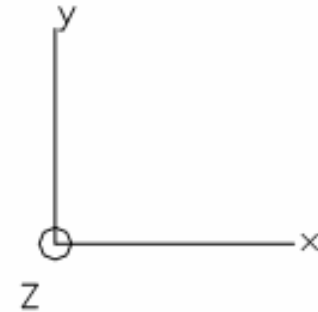




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Problem formulation





Mathematical model

Angular momentum of each disk

$$H_1 = I_1 \omega_1 = \left[\frac{1}{2} m r^2 + m d^2 \right] [-\omega_1]$$

$$H_2 = I_2 \omega_2 = \left[\frac{1}{2} m r^2 + m d^2 \right] [\omega_2]$$

M = Mass of the space craft

m_i = mass of the reaction wheel

ω_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

$$I \ddot{\theta} = (M r^2 + 2 M d^2) \ddot{\theta}$$



Mathematical model

Conservation of angular momentum

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

$$\frac{d}{dt} \left[\left(\frac{1}{2} m r^2 + m d^2 \right) (-w_1) + \left(\frac{1}{2} m r^2 + m d^2 \right) (w_2) \right] = (M r^2 + 2 M d^2) \ddot{\theta}$$

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

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

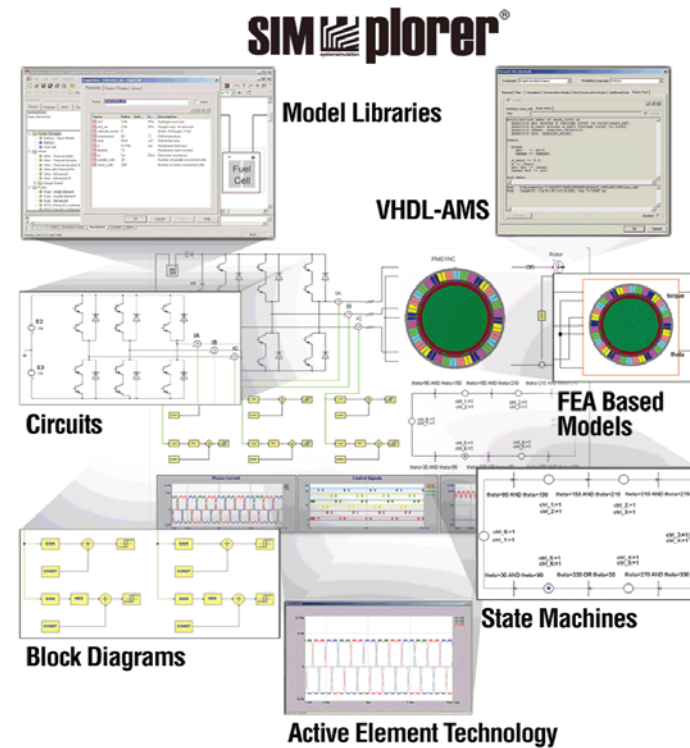


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Simplorer

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





Outline

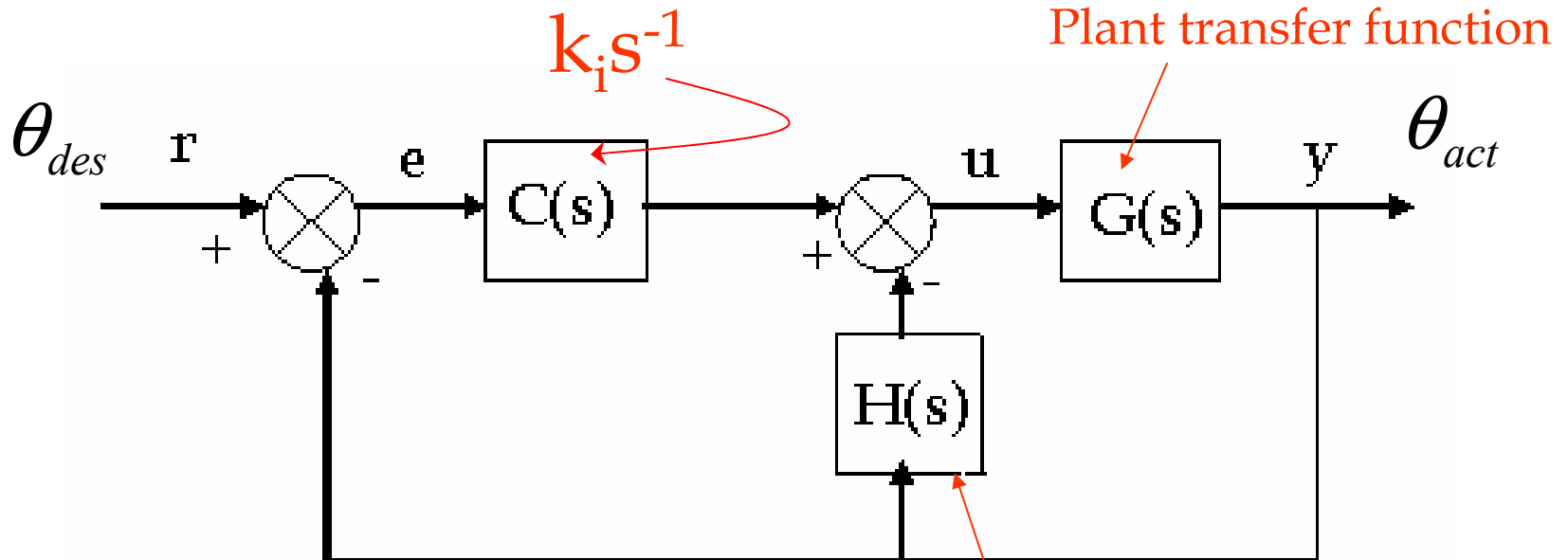
1. Overview of Attitude Determination and Control system
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Modified PI Controller

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

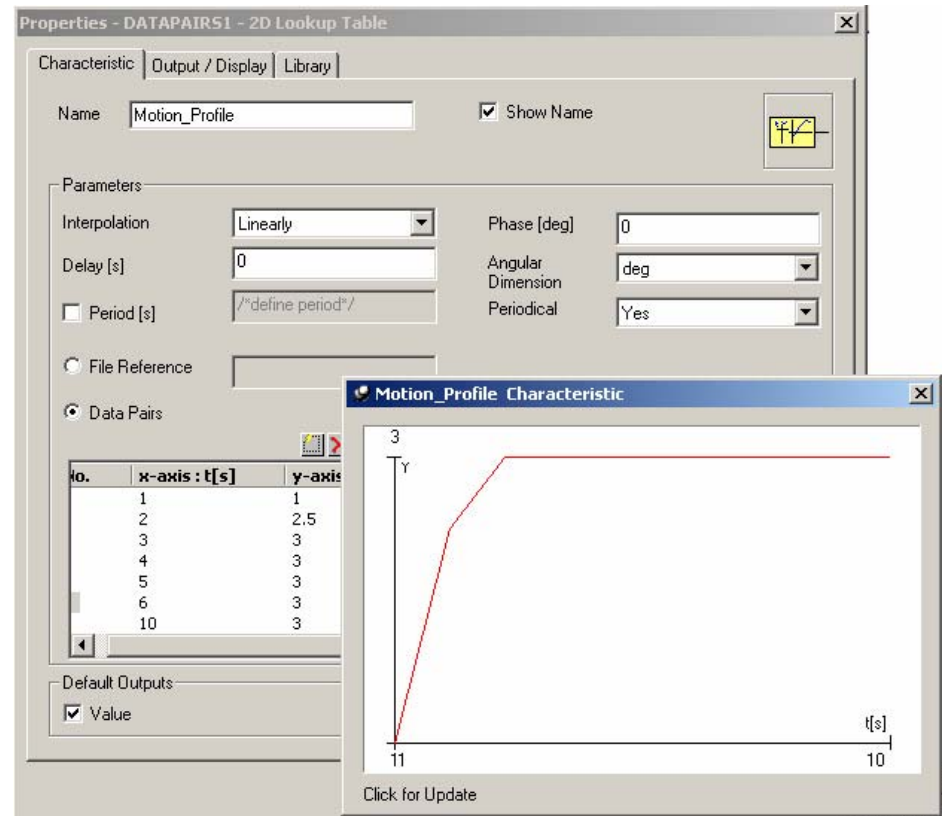
*Reference: A Robust Two-Degree-of-Freedom Control Design
Technique and its Practical Application
-Robert Miklosovic, Zhiqiang Gao*



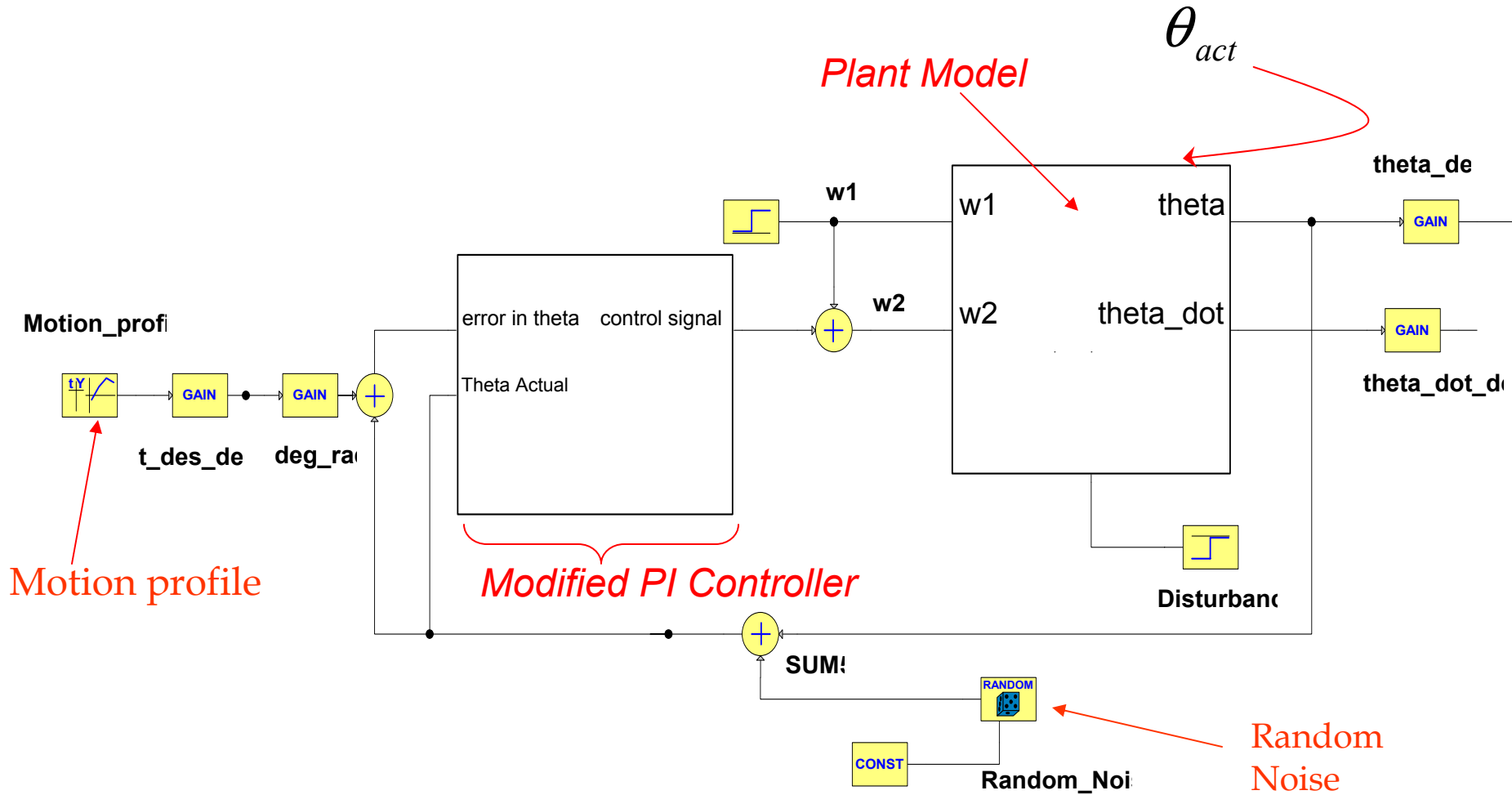
$$(\theta_{des} - \theta_{act}) \cdot \frac{k_i}{s} - k_p \cdot \theta_{act} = (\theta_{des} - \theta_{act}) \cdot \frac{\omega_c^2}{s} - 2 \cdot \omega_c \cdot \theta_{act}$$

Motion profiling

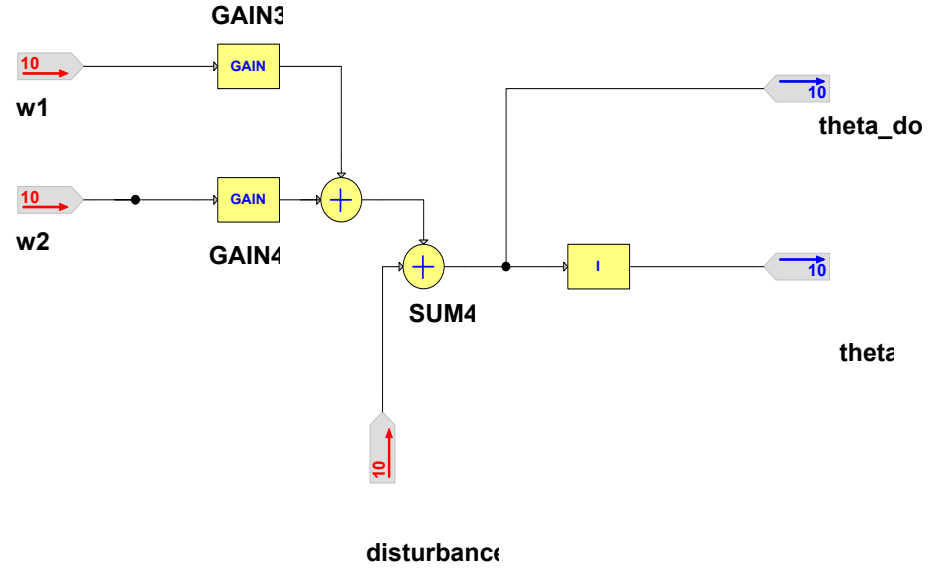
- The desired trajectories as the command input in the closed loop control
- In this case, a profile generator is used to produce desired angle to the system
- Motion profile is used instead of step.



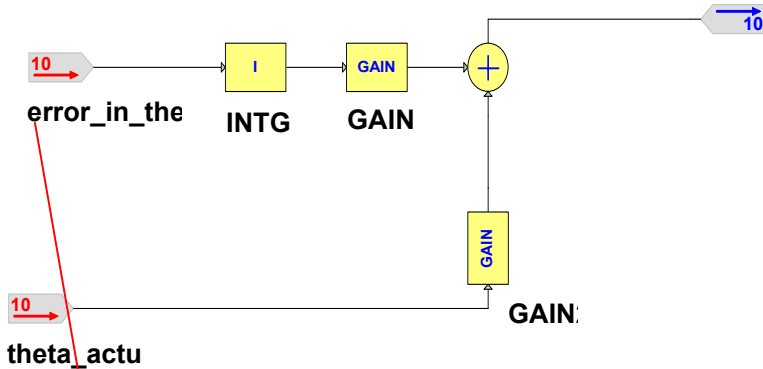
Simulation Results



Plant Model



Modified PI Controller

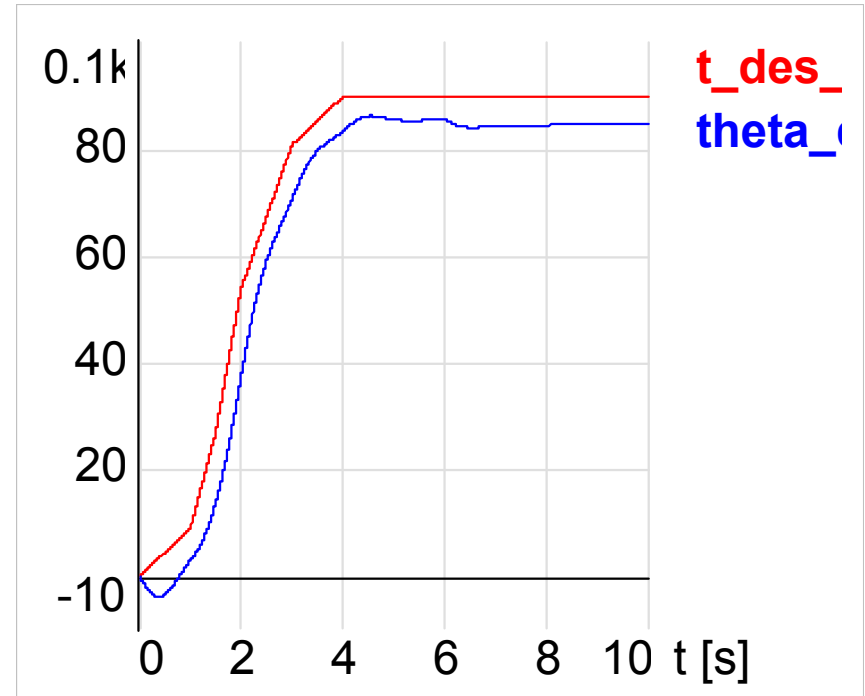
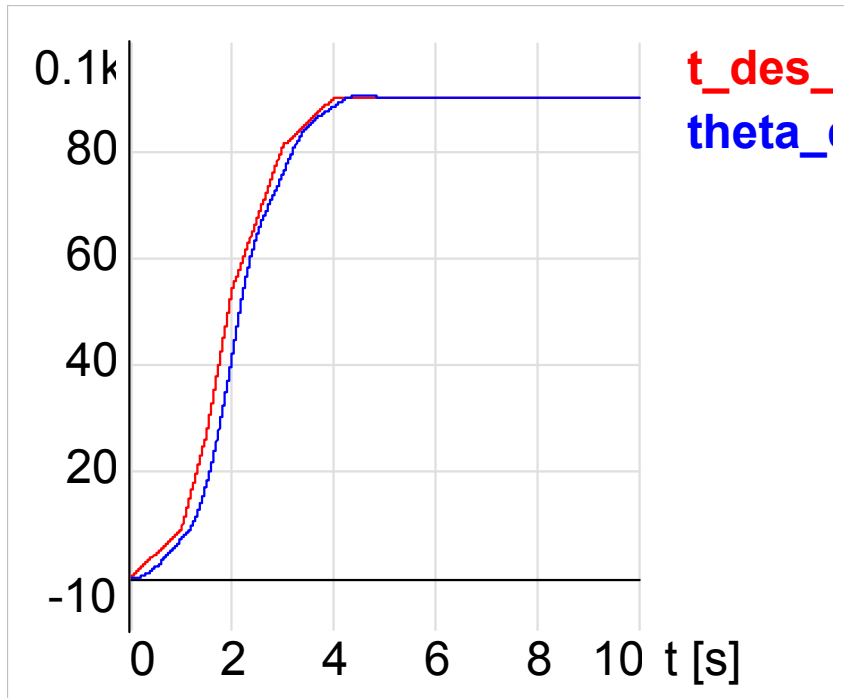


$$(\theta_{des} - \theta_{actu}) \cdot \frac{k_i}{S} - k_p \cdot \theta_{actu} = (\theta_{des} - \theta_{actu}) \cdot \frac{\omega_c^2}{S} - 2 \cdot \omega_c \cdot \theta_{actu}$$

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

Simulation Results

Theta Actual & desired

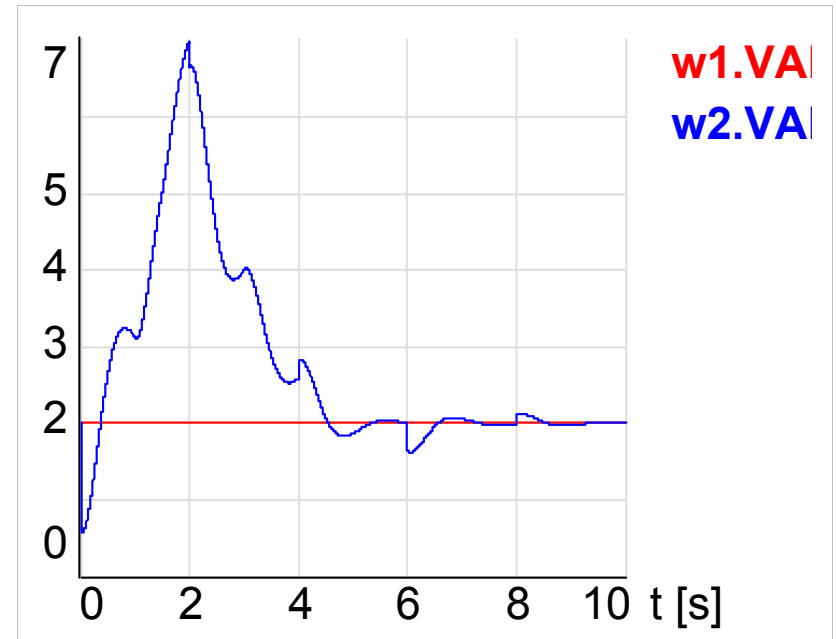
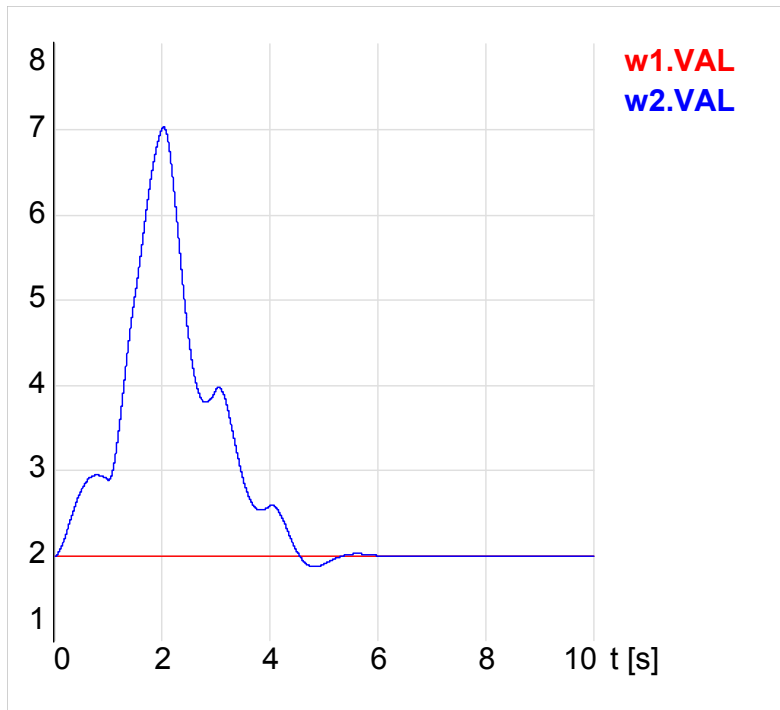


Noise amplitude: 0.07 - 0.1

Noise interval: 2 sec

Simulation Results

control inputs w1 and w2



Noise amplitude: 0.07 - 0.1

Noise interval: 2 sec



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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



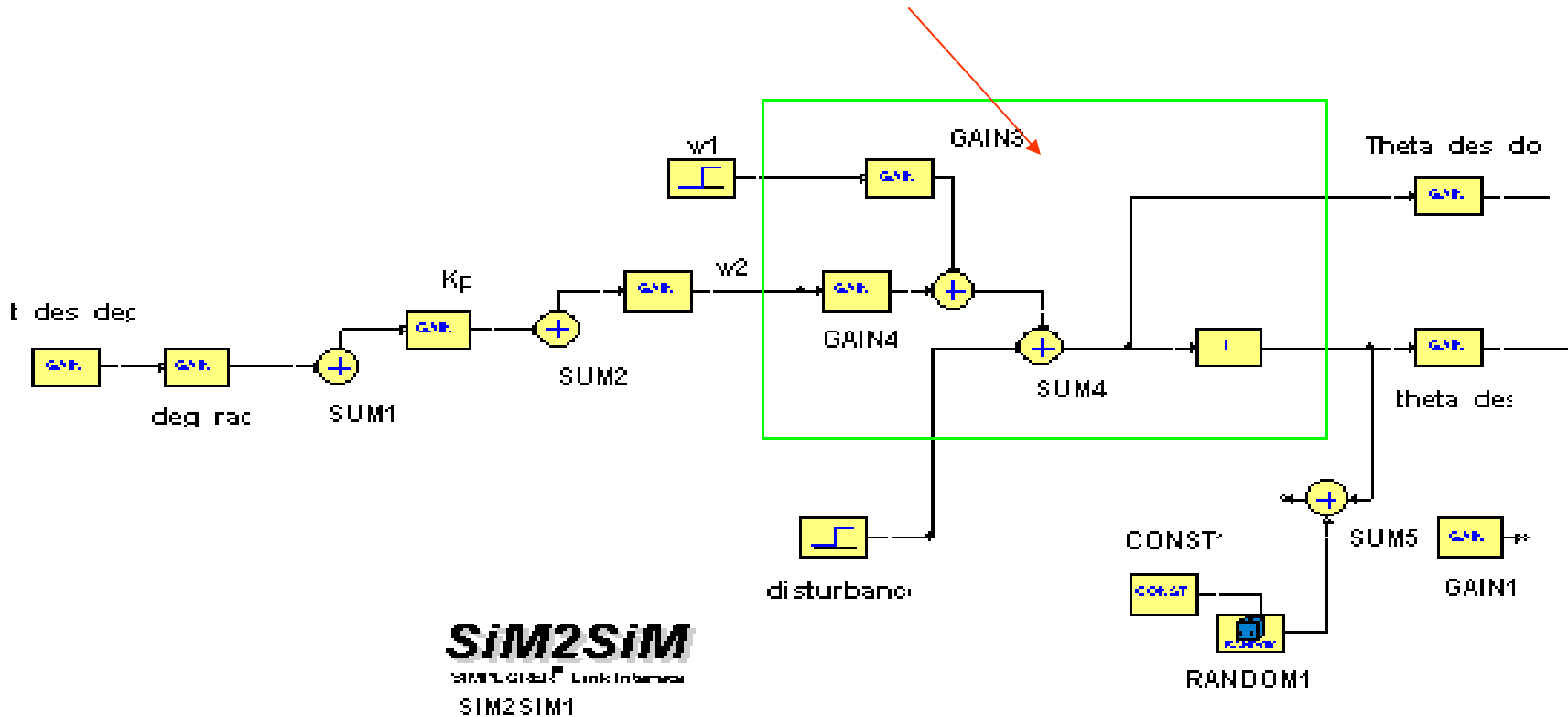
Extended State Observer

- 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

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

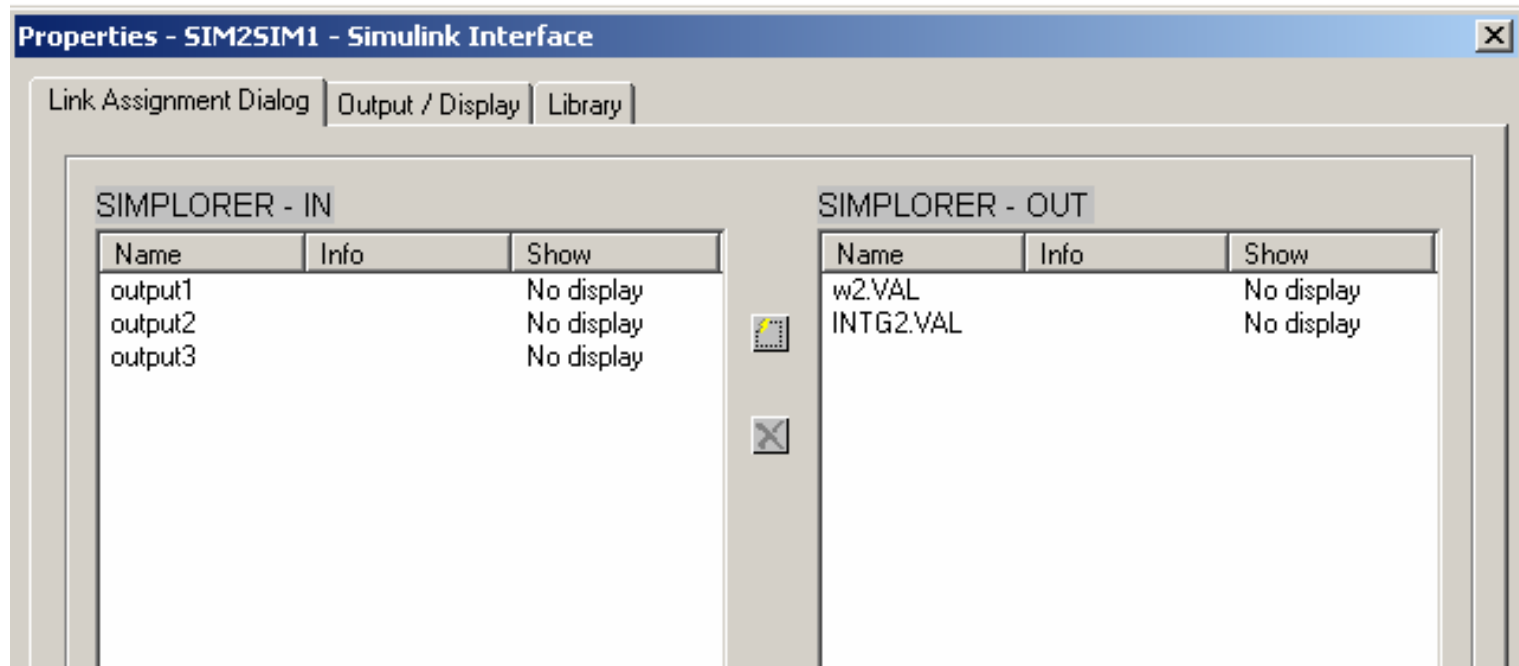
Simulation Results

Plant Model

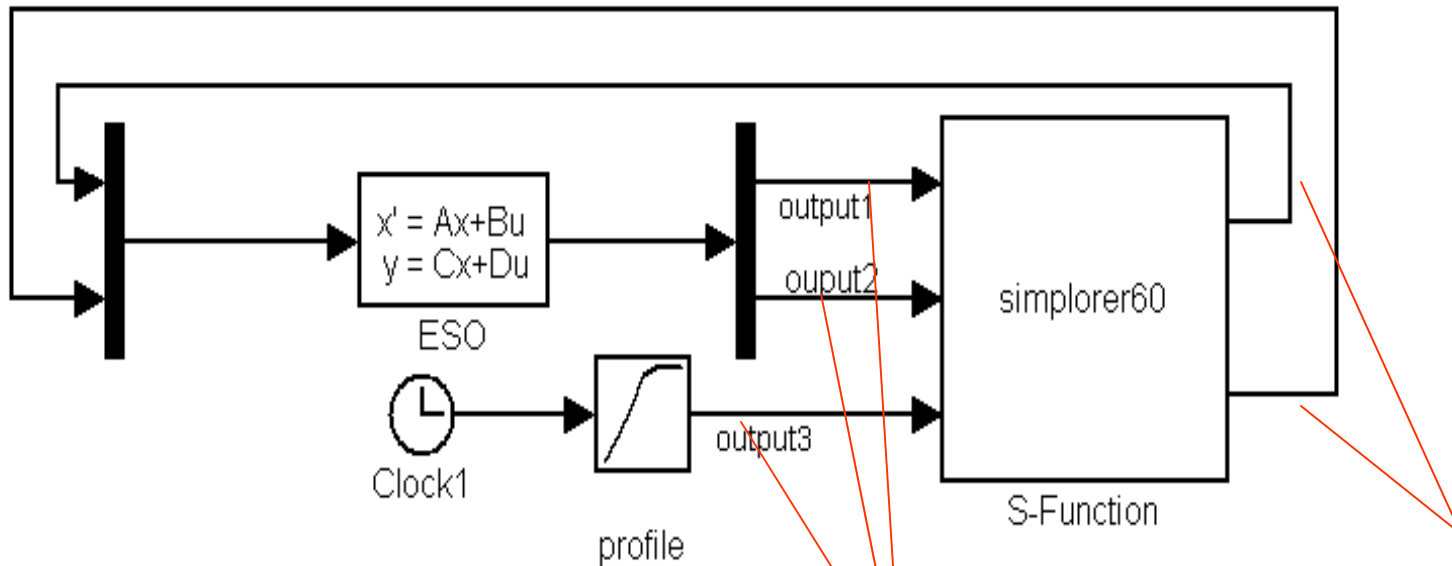


Simplorer and Matlab

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



Matlab/Simulink Model

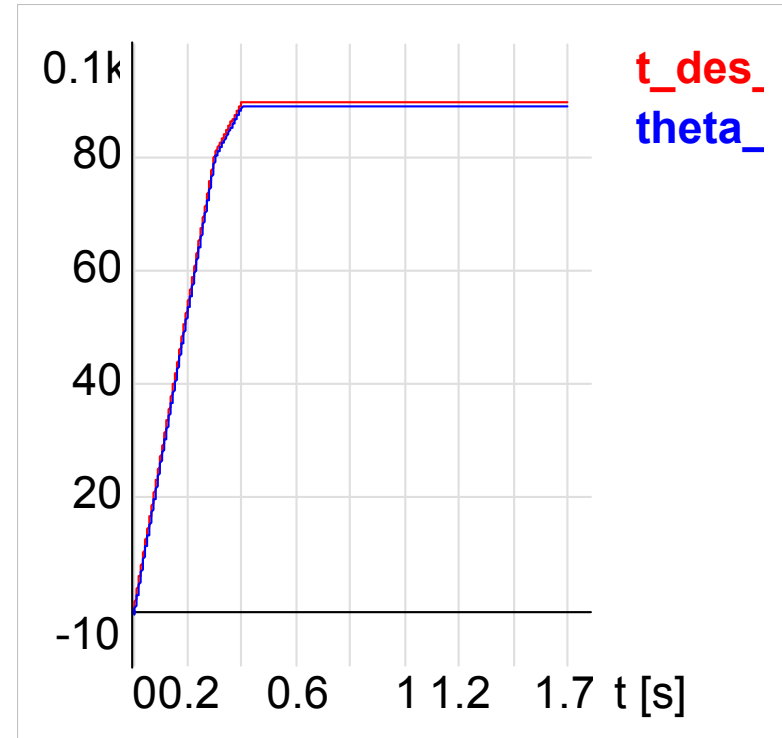
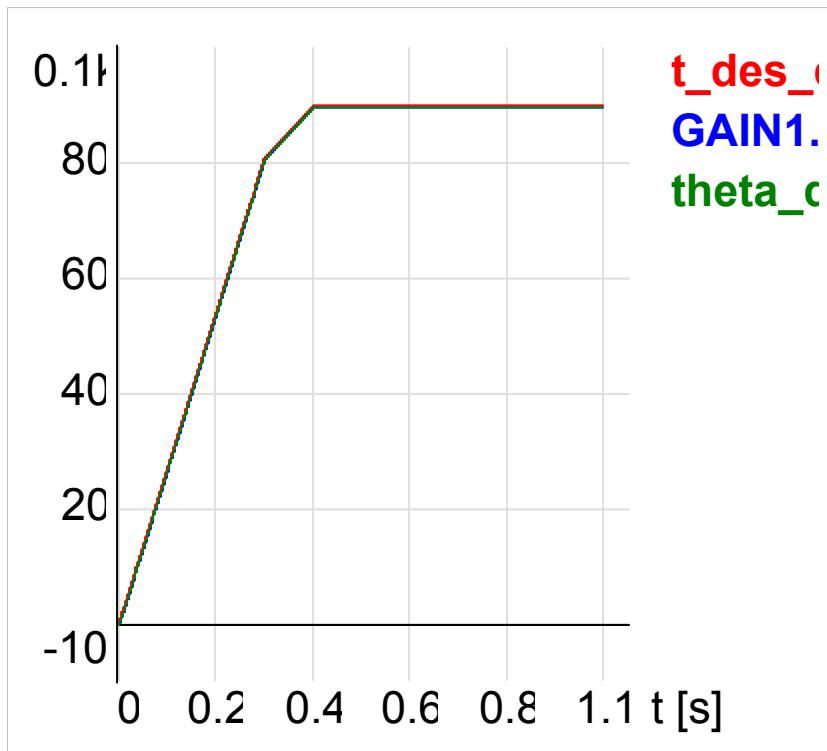


Inputs to the
simplorer

Outputs from
the Simplorer

Simulation Results

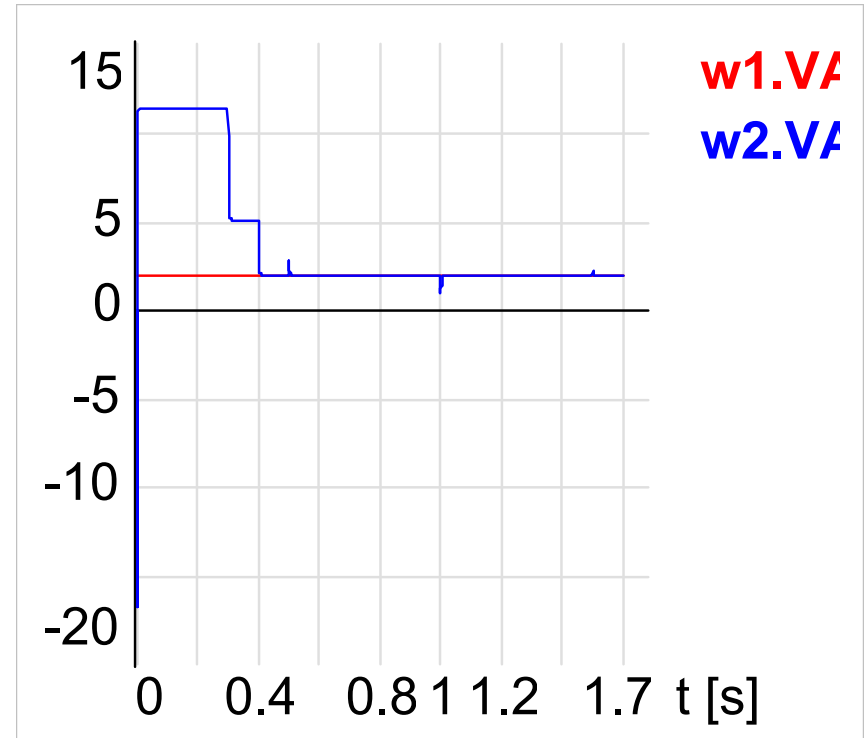
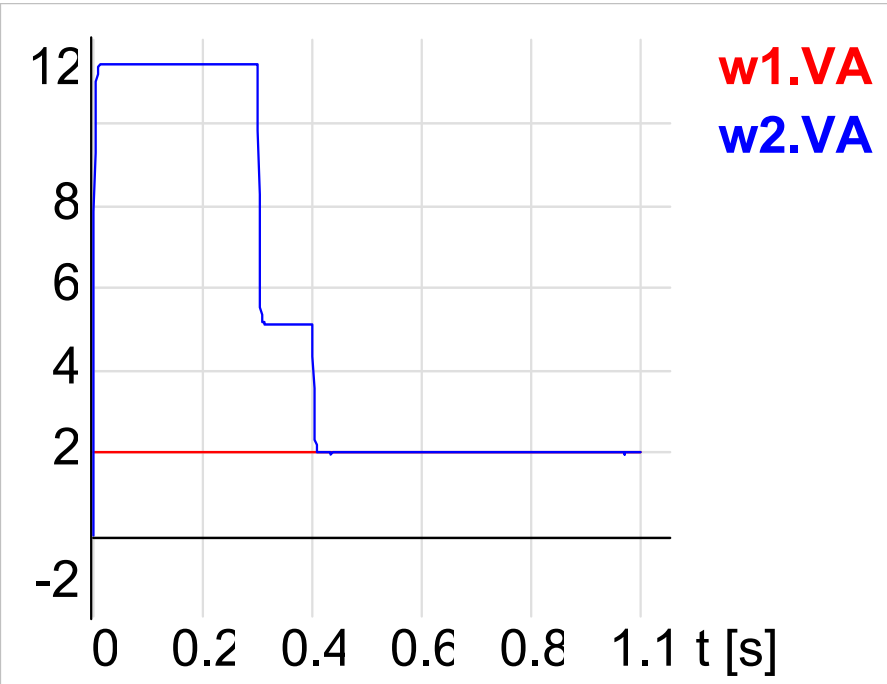
Theta Actual and Theta desired



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