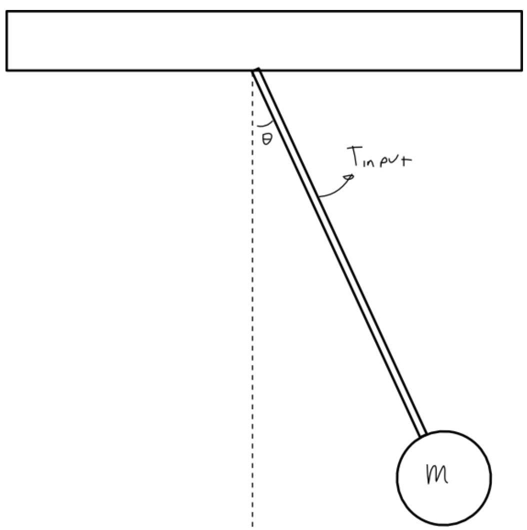
System Modeling Using Simscape

An introduction to Simscape

Simscape is a GUI modeling environment for multi-domain physical systems where object behaviors are predefined and governed by relevant physical laws. The user does not need to derive the mathematical model of the system. Simscape objects are available in the Simulink library browser under Simscape. Several toolboxes exist for modeling systems in different physical domains.

EXAMPLE: Modeling a pendulum

Consider the pendulum as shown:



Mathematical model of the system:

Using Newton's law (and considering viscous friction losses and a spring force):

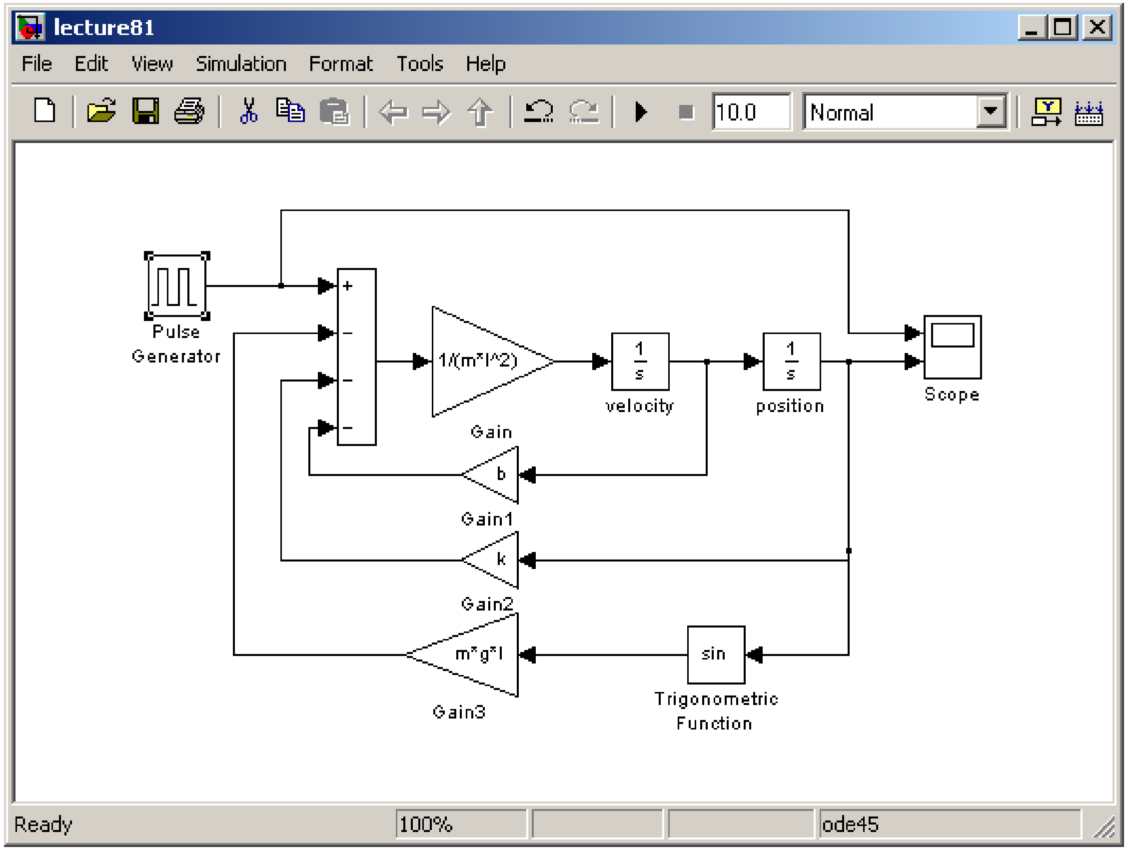
$$Torque\ due\ to\ gravity:\ T_g = mgl\ sin\theta$$
$$Torque\ due\ to\ friction:\ T_f = b\dot{\theta}$$
$$Position\ dependent\ torque: T_k = k\theta$$

$$I\ddot{\theta} = \Sigma T; I_{pendulum} = ml^2$$
$$ml^2\ddot{\theta} = T_{input} - k\theta - b\dot{\theta} - mgl\ sin\theta$$

Simulink Modeling of Pendulum

<u>Simulink model</u>:

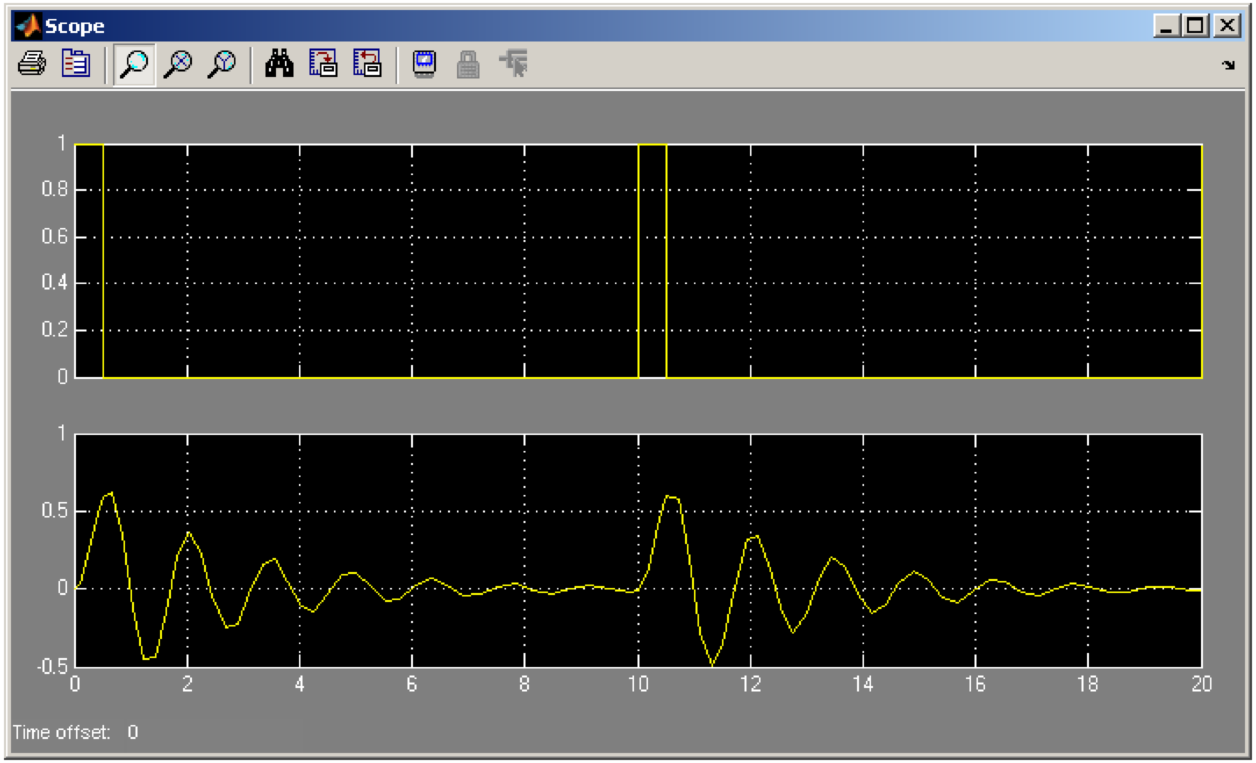
- The pendulum is a nonlinear system, and since we derived its mathematical model, we can build it in Simulink as:



Simulink Modeling of Pendulum …

Simulation with Simulink:

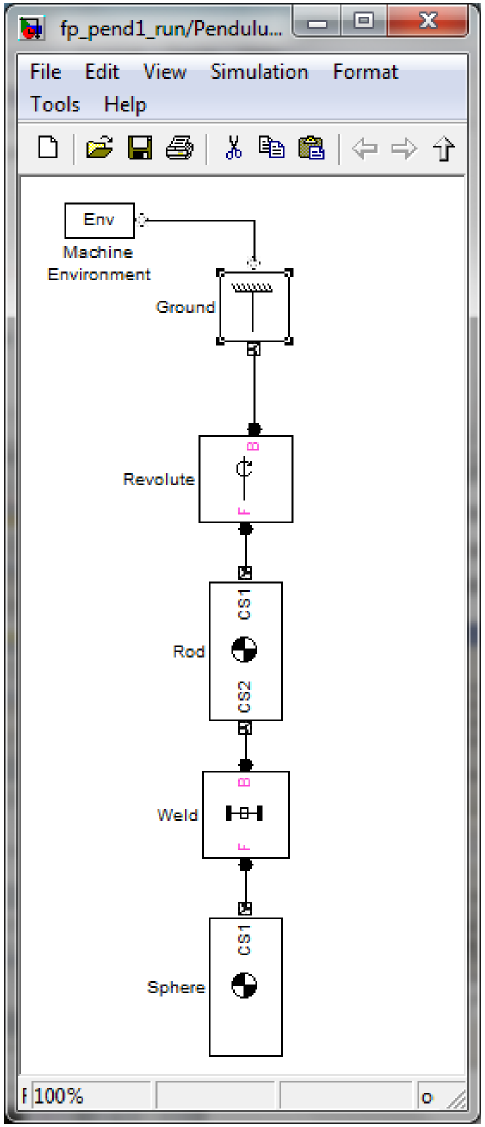
- Define values for the system parameters
  - m=0.5kg, l=0.5m, g=9.81m/s^2, b=0.1, k=0
- Run the Simulink model and plot the system response (angular position) to an input torque pulse.



Simscape Modeling of Pendulum

Simscape model:

- Modeling a system in Simscape does not require deriving the mathematical model of the system based on the physical laws
- To model the pendulum in Simscape, open the SimMechanics library and get:
  - One environment object
  - One physical reference object (ground)
  - Two physical bodies (the rod and the sphere)
  - Two joints for connecting the bodies (one fixed, one rotational (single axis))
- Connect these objects as shown



Simscape Modeling of Pendulum …

- Define the physical ground reference w.r.t. the environment
  - In the ground object's parameter window enable the environment port
- Define gravity as acting along the z-axis
  - In the environment object's parameter window, enter: [0,0,-9.81]
- Define the pendulum's axis of rotation w.r.t. the environment
  - In the joint object's parameter window, enter: [0,1,0] , (y-axis w.r.t. the world)
- Define the endpoints and the center of gravity (COG) of each body with respect to an adjoining body
  - The positions of objects should all be defined w.r.t. their adjoining bodies
- Define the moment of inertia of each body
  - Moment of inertia of each body is expressed as a square matrix. For example:

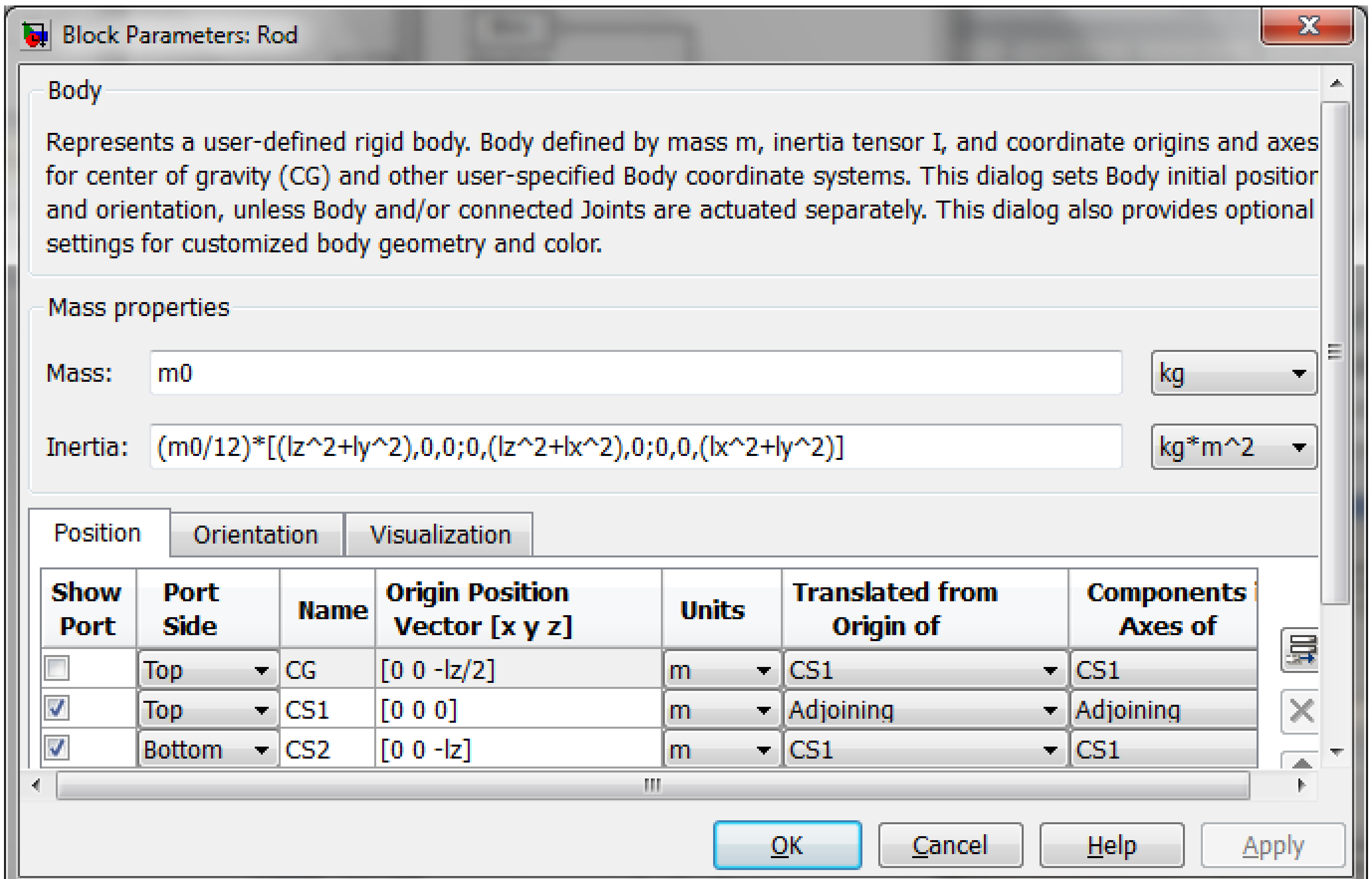
$$\begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}, \quad where \begin{cases} I_{xx}: moment\ rotating\ about\ x-axis \\ I_{yy}: moment\ rotating\ about\ y-axis \\ I_{zz}: moment\ rotating\ about\ z-axis \end{cases}$$

Tables of inertia moments are available online.

Simscape Modeling of Pendulum …

Setting up parameters for the pendulum’s body (rod):

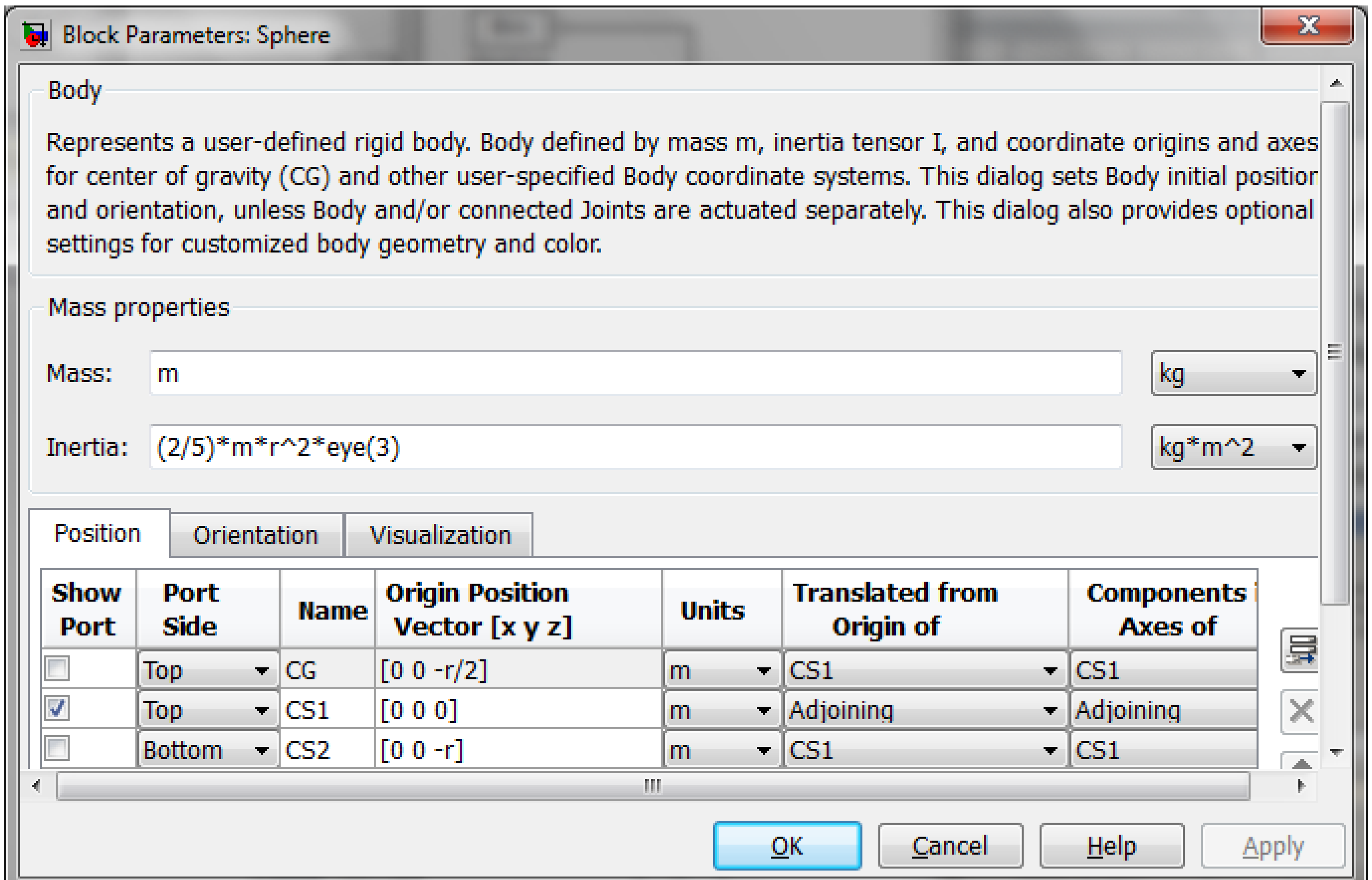
- In the parameter window of the rod’s body object define its mass and moment of inertia, and set the relative position of its center of gravity (COG) and its ends with respect to the adjoining body (the reference ground)



Simscape Modeling of Pendulum …

Setting up parameters for the pendulum’s spherical end:

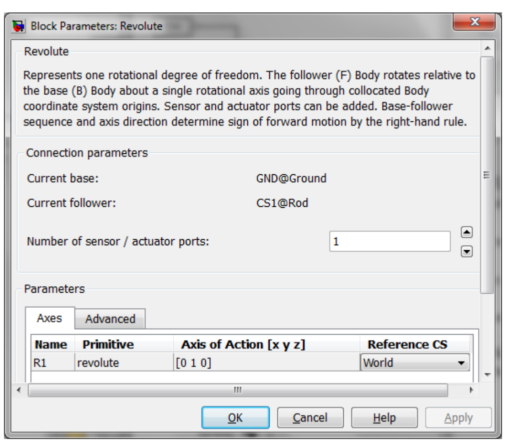
- In the parameter window of the spherical body object, define its mass and moment of inertia (to rotate about its center), and set the relative position of its center of gravity (COG) and its ends with respect to the adjoining body (the rod)
    - Note that the COG of the sphere is exactly at the endpoint of the rod

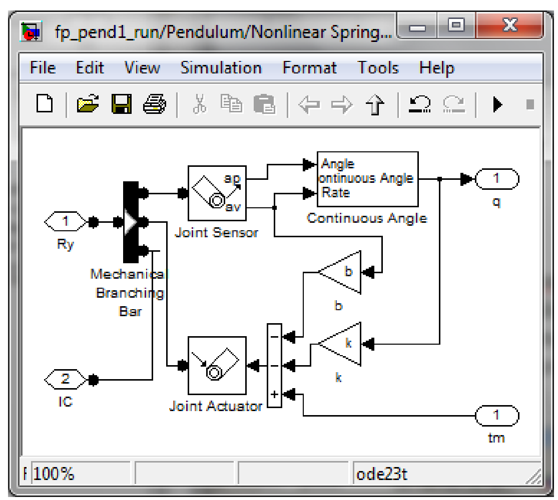


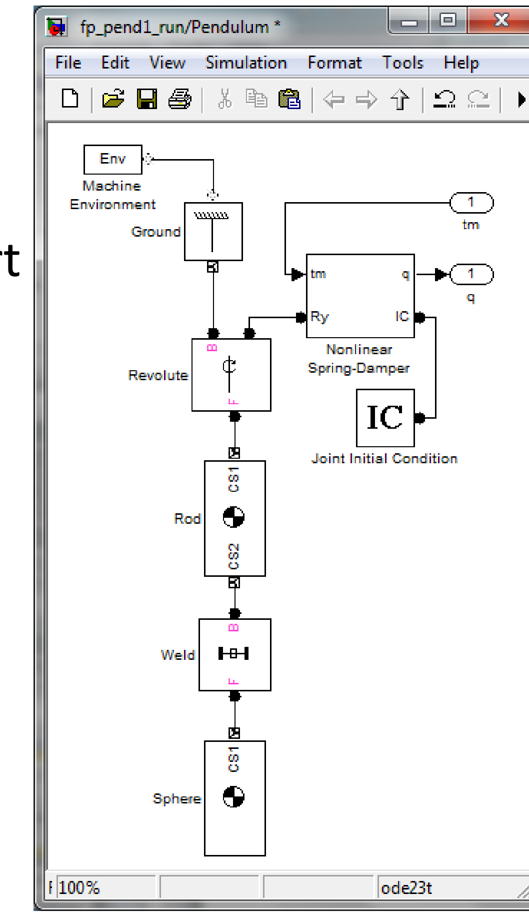
Simscape Modeling of Pendulum …

Adding Simulink blocks for input/output interface:

- In the Revolute Joint’s parameter window, add a sensor port
- Add a Joint Actuator and a Joint Sensor object from the SimMechanics library
    - Joint actuators and sensors interface with Simulink
        - For example, to apply forces and to observe the pendulum’s rotation angle
- Add a Machanical Branching Bar object to connect the joint sensor and joint actuator to the revolute joint’s port
- You may also add
    - An IC block
    - A continuous angle block



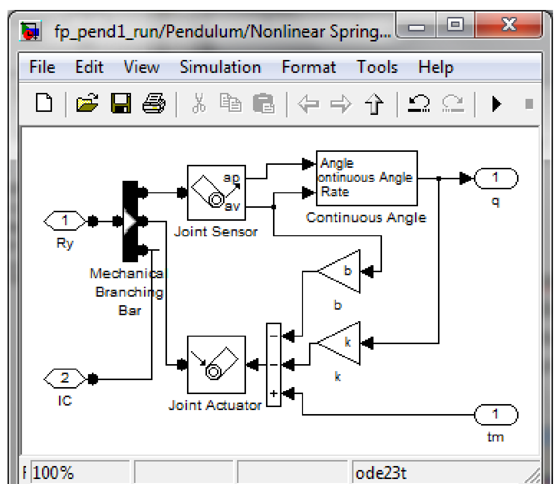


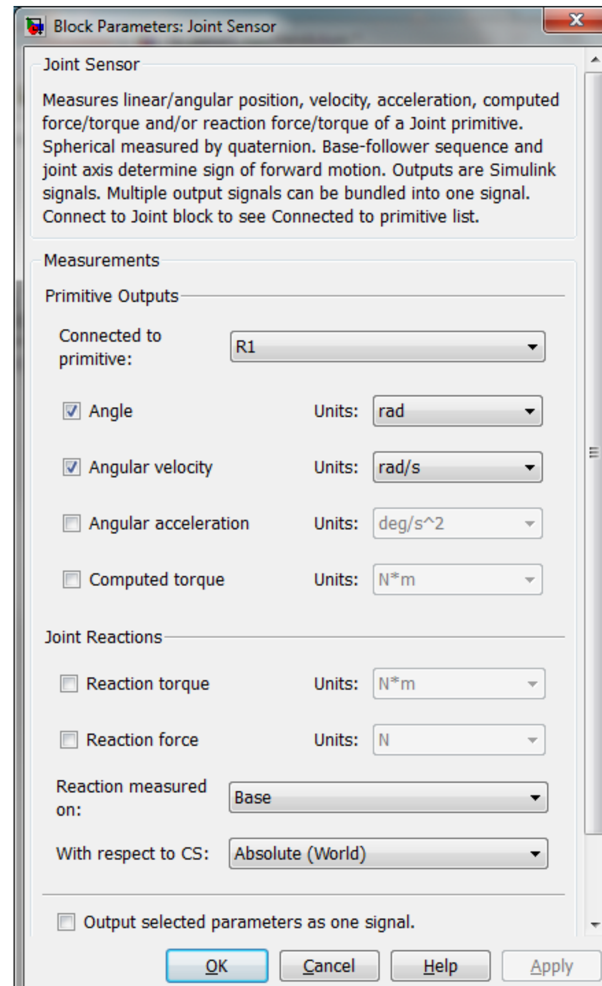


Simscape Modeling of Pendulum …

Setting up parameters of the joint sensor:

- In the joint sensor’s parameter window, select both the angle and angular velocity sensors
- De-select ‘Output selected parameters as one signal’ for individual access
- Add an external input torque from Simulink
- Apply a feedback torque to the joint as a combination of the external torque, angular position and angular velocity (due to torsional spring and friction)





Simscape Simulation of Pendulum

Step for simulation:

1. Define the parameter values (bodies' mass and dimension, spring and friction constants, etc.) (m0=0.001; lz=0.5; ly=0.01; lx=0.01; m=1; r=lz/10; k=1; b=0.1; g=9.81;)
2. Enable animation in SimMechanics node, via configuration parameters dialog in simulation menu
3. Start simulation
   a) Animation of the physical bodies is shown in a window
   b) Input/output data is recorded via Simulink interface

Simulation plots and animation