Hochschule
Kaiserslautern
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M.Sc. in Mechatronics engineering

System level rapid development in mechatronics
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(Milestone-1)

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MATLAB/Simulink model of the two-wheel robot

Section 1: Multi Body Simulation

a) ***Introduction:***

To begin modeling the two-wheel robot, MATLAB/Simulink must be installed on a Windows system with the following toolboxes configured for Milestone M1:

- Simscape Multibody Toolbox – for physical modeling of mechanical systems
- Control System Toolbox – for designing and analyzing control systems
- Control Design Toolbox – for tuning and validating control algorithms
- Design Optimization Toolbox – for parameter optimization and system tuning

These toolboxes enable a comprehensive simulation environment for dynamic modeling and control design.

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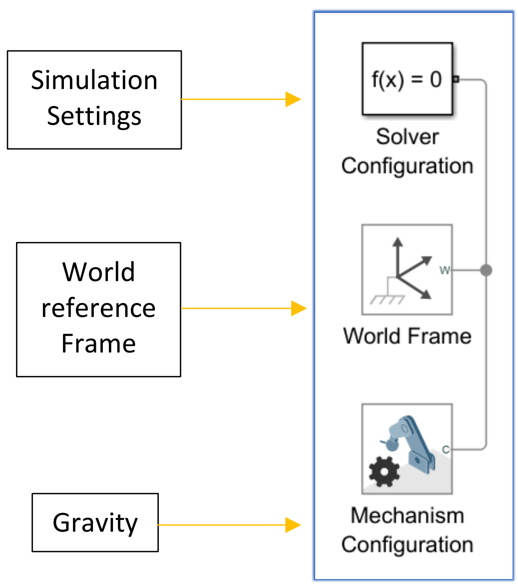
b) Base body & pendulum design:

The simulation setup starts with essential Simscape blocks:

- In the initial stage, set up the work environment by using the blocks like Solver configuration, World frame and Mechanical configuration.



- Solver Configuration – defines simulation parameters and solver settings
- World Frame – establishes the global reference frame
- Mechanism Configuration – sets gravity and other physical properties

These blocks are interconnected to form the foundational simulation environment. The diagram illustrates the flow from simulation settings and world reference to the solver configuration.

To simulate the pendulum system accurately, the base body and pendulum are modeled with precise dimensions and coordinate settings.

Base Body dimensions.

- Length(X) = 0.05m
- Breadth(Y) = 0.05m
- Height (Z) = 0.05m

Visualization Enhancements:

- Opacity is adjusted to help identify the coordinate system and joint placements during simulation.
- Color coding is applied to the base block for easy identification.

Coordinate System Placement:

- A new coordinate system (CS) is positioned 2 cm above the base body to enable rotational motion for the pendulum.

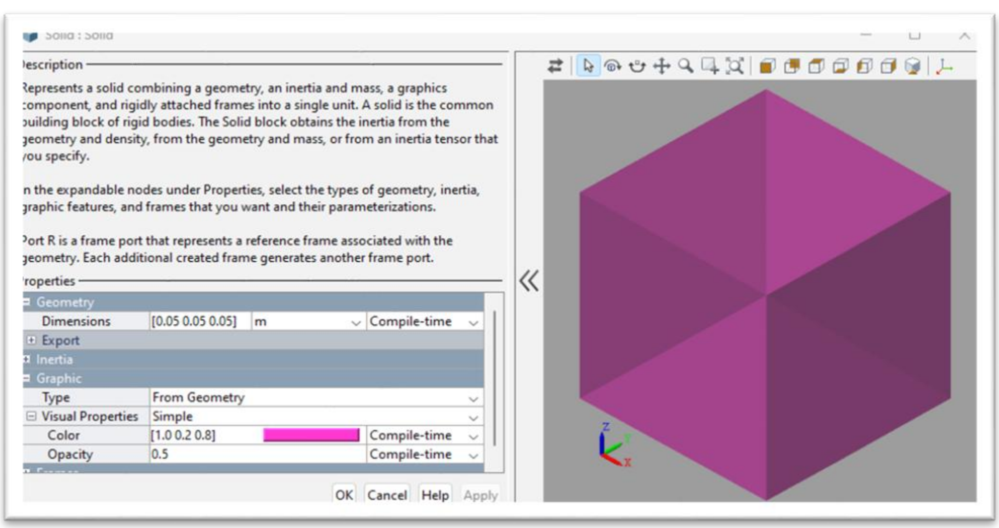


Fig 1: Base body

Pendulum design.

- Length(X) = 0.3m

- Breadth(Y) = 0.02m
- Height (Z) = 0.02m

This configuration ensures that the pendulum can rotate freely around the designated axis while maintaining structural clarity in the simulation environment.

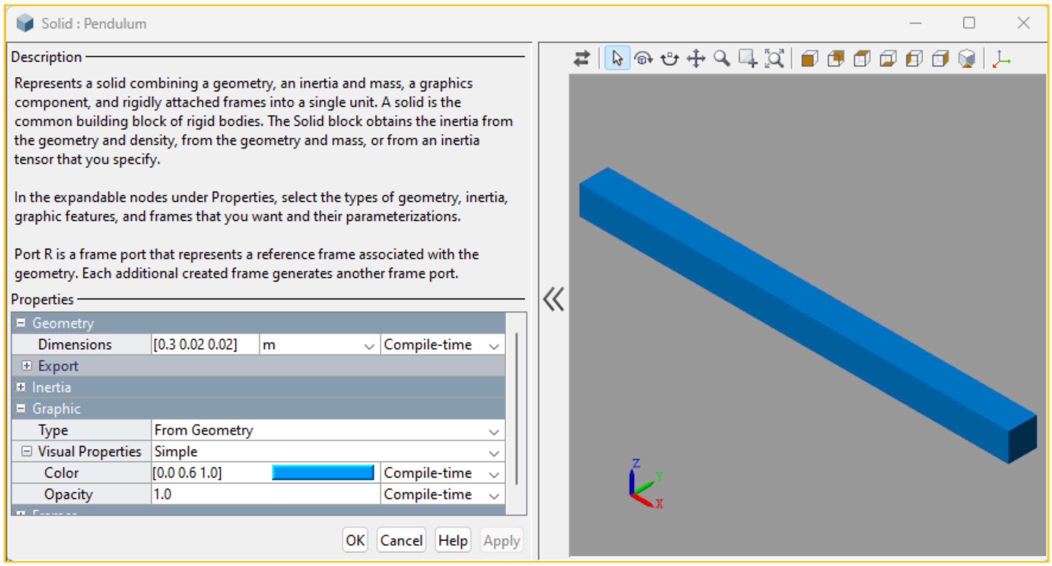


Fig 2: Pendulum

- A new coordinate system is established 1 cm in front of the base body to enable rotational motion for the pendulum. This placement ensures proper alignment and dynamic behavior during simulation.
- The inverted pendulum is initially positioned in an upright orientation, with a deliberate 5° offset from vertical to simulate an unstable equilibrium and trigger dynamic response.

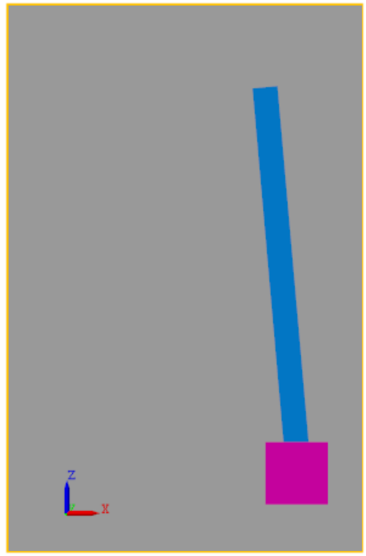


Fig 3: Inverted pendulum

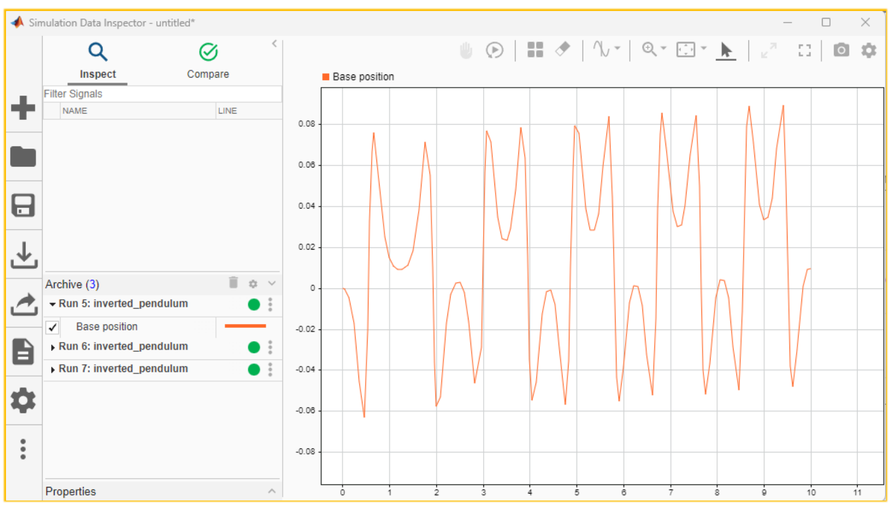


Fig 4: Base position graph

c) Actuation:

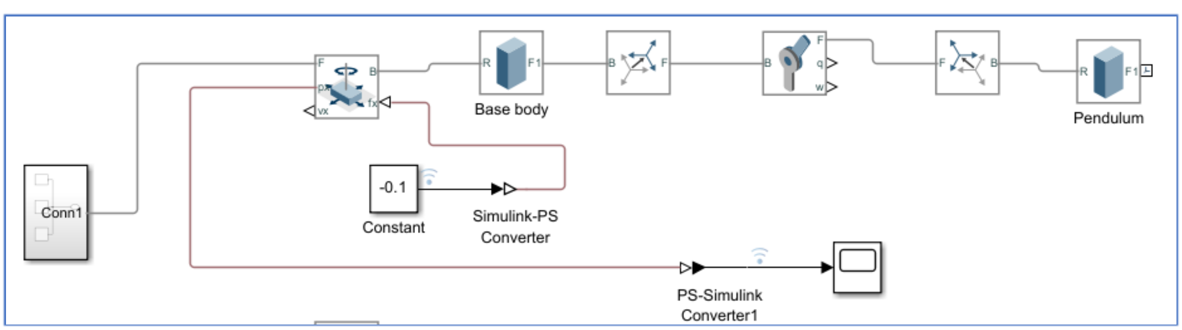


Fig 5: Actuation at planar joint

To simulate the pendulum's dynamic response, actuation forces are applied directly at the planar joint using Simulink and Simscape components.

- Constant values of **+0.1 N** and **−0.1 N** are applied to the planar joint to induce motion. These forces are introduced using a **Constant block** connected through a **Simulink-PS Converter**, and the resulting physical signals are fed back via a **PS-Simulink Converter**.
- The goal is to observe and compare the pendulum's behavior under opposing actuation forces. The results are visualized in the subsequent graph to analyze system response and stability.

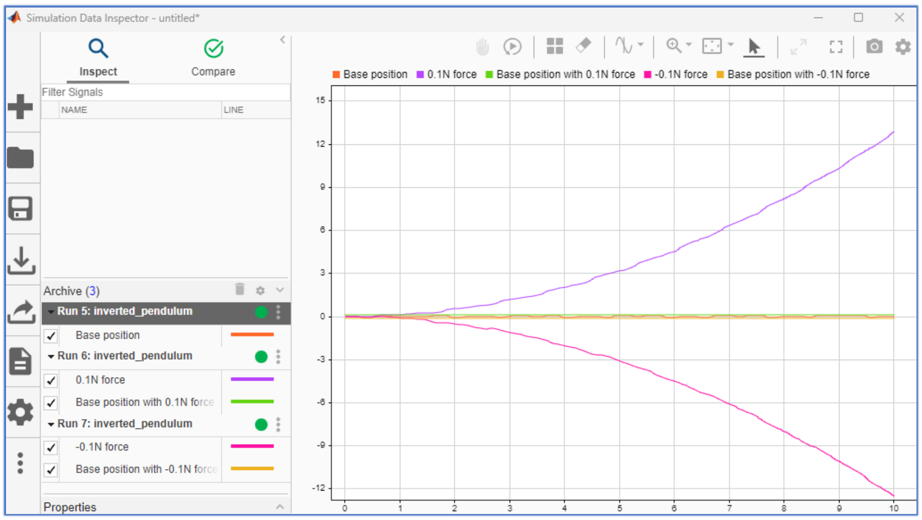


Fig 6: graphs for actuation at planar joint

Section 2: Control design

To implement and test control strategies for the two-wheel robot, the following toolboxes are required:

- Simscape Multibody Toolbox
- Control System Toolbox
- Control Design Toolbox
- Design Optimization Toolbox

These enable dynamic modeling, controller synthesis, and performance tuning within the Simulink environment.

a) State Space representation:

The system is modeled using state-space notation, which defines the physical system through a set of inputs, outputs, and state variables governed by differential equations. This mathematical framework is essential for designing and analyzing control systems.

b) Building and optimizing the controller & linearizing the simscape multibody model:

To prepare the system for control implementation:

- The planar joint is replaced with a prismatic joint to simplify linearization and control input application.
- Signals from the revolute joint specifically angle and angular velocity are extracted using PS-Simulink Converters and routed to Gain blocks and Scopes for monitoring.
- The base velocity from the prismatic joint is connected to one input of an Add block.
- The base position is also logged via a PS-Simulink Converter and routed to a Gain block.
- A Pulse Generator is connected to the second input of the Add block to simulate a target velocity profile with the following parameters:

  Amplitude = 0.2
  Period = 4 sec
  Pulse width = 50 % of period

The output of the Add block is then fed into the input Gain block, completing the control loop.

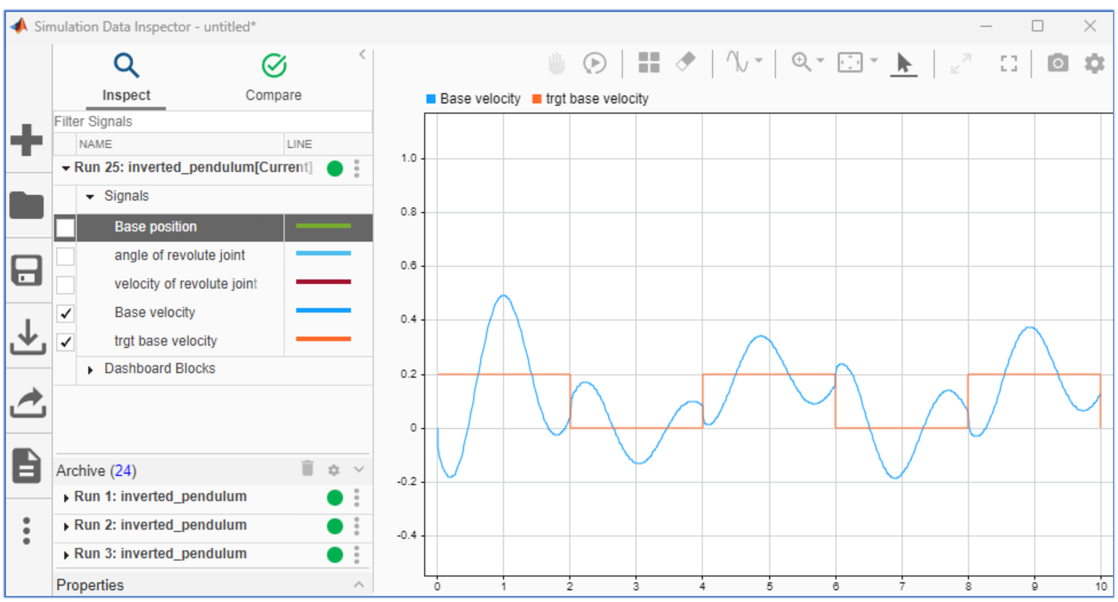


Fig 7: Graph b/w base & target velocities

To stabilize the system and achieve accurate velocity tracking:

- State variable outputs (e.g., angle, angular velocity, base velocity, base position) are extracted via PS-Simulink Converters.
- These signals are routed to Gain blocks and a Subtract block, which computes the error between actual and target velocities.
- The resulting error signal is used as an open-loop input force to the prismatic joint, enabling corrective actuation.
- The system is tuned to maintain the pendulum in an upright position, with the angle output stabilized at zero.
- The gain values of the variables are altered in such a way that the system reaches almost stable condition. Those obtained values are as follows:
  Gain angle of revolute joint = 9
  Gain Velocity of the revolute joint = 8.5
  Gain base velocity = -11
  Gain base position = 0

- The blocks connections are mentioned in the below diagram.

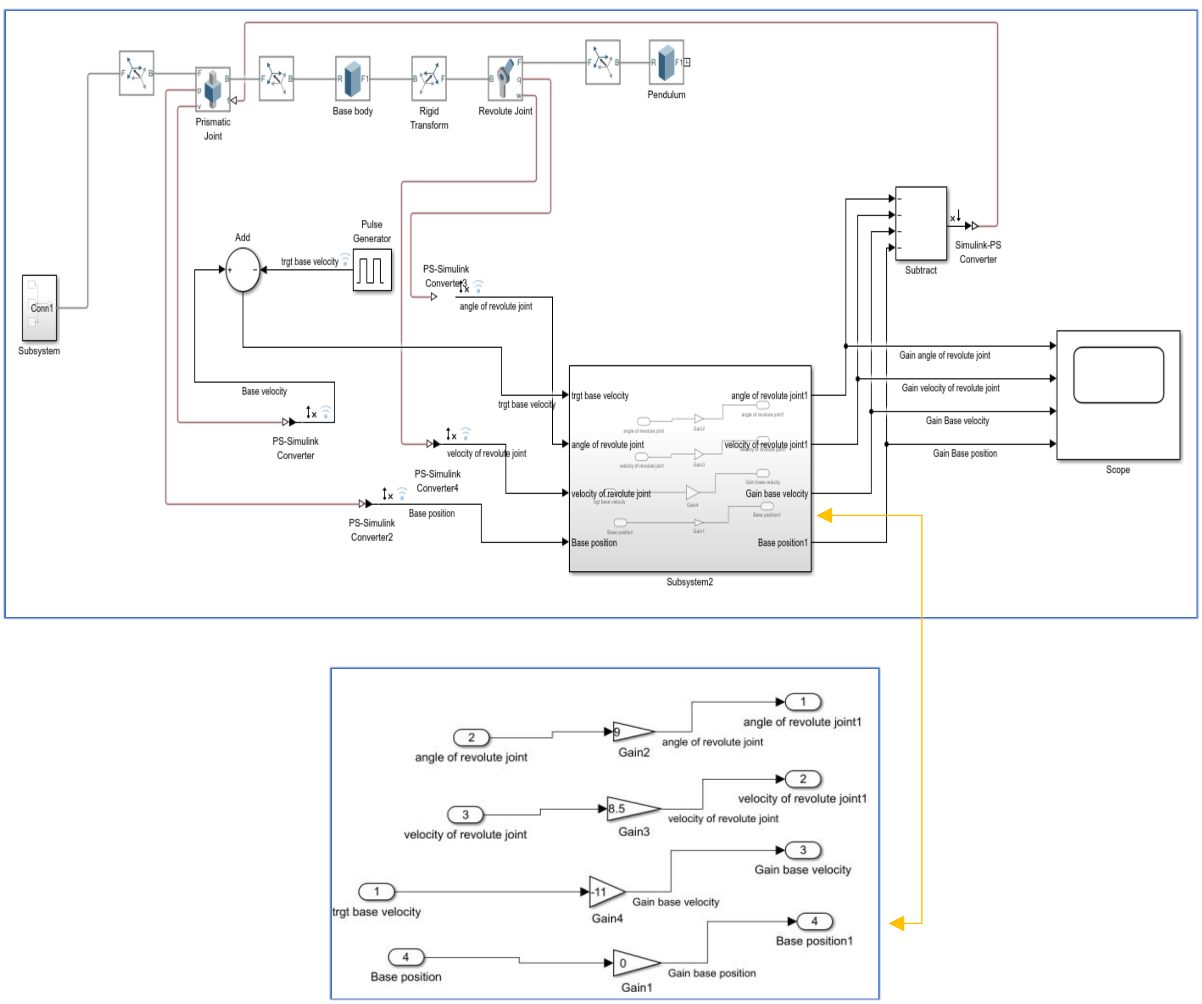


Fig 8: Block diagram connections

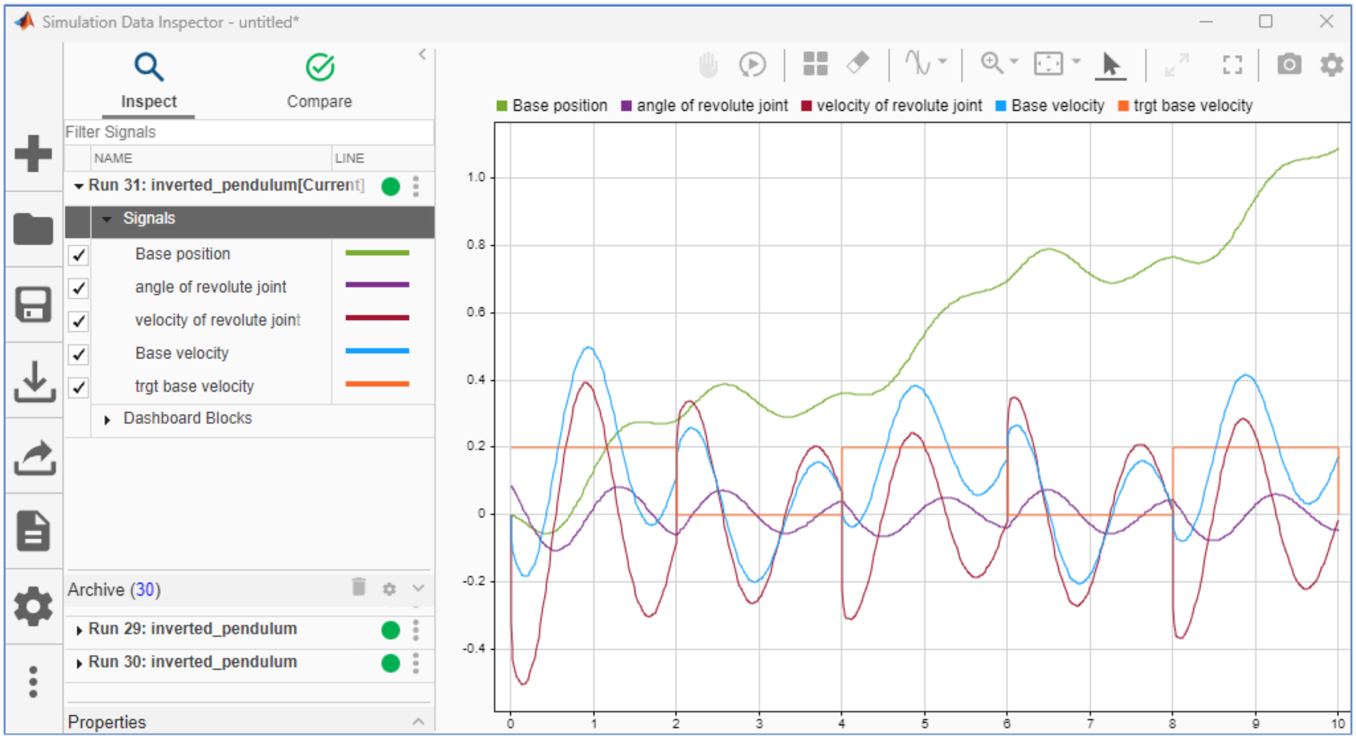


Fig 8: Final graphs from data inspector

The simulation successfully demonstrates dynamic control of the inverted pendulum, with real-time tracking of base and joint variables.

- Target base velocity is closely followed by the actual base velocity, indicating effective actuation and controller tuning.
- The angle and velocity of the revolute joint stabilize over time, confirming that the pendulum reaches and maintains its upright position.
- The use of Simulink Data Inspector provides valuable insights into system behavior, enabling precise performance evaluation.
- Gain values were carefully tuned to achieve stable equilibrium, minimizing oscillations and ensuring smooth response.
- The control architecture combining state-space modeling, open-loop force input, and signal feedback proves robust for real-time simulation and optimization.