Two wheeled Self-balancing Robot using LEGO NXT Kits

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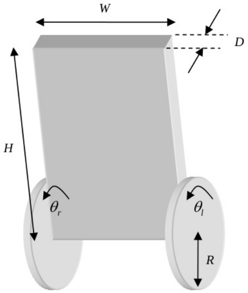
LEGO 2-Wheel Self-balancing Robot

Using

1. LEGO Mindstorms NXT 2.0 Kit
2. HiTechnic Gyro Sensor
3. Simulink (with Hardware Support Package for LEGO NXT)

Figure : LEGO 2-Wheel Self-Balancing Robot - NXTway-GS

Mathematical Modelling - Diagram



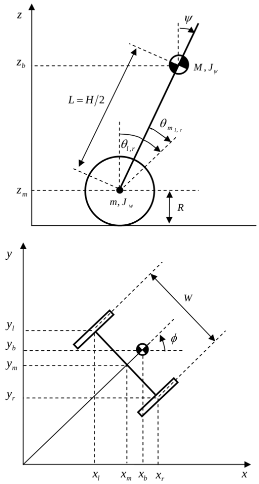


Figure : Two-wheeled Inverted Pendulum model - (clockwise from left) Perspective view, side view and top view

Mathematical Modelling - Equations of Motion

The equations of motion are derived using Lagrangian dynamics.
The Lagrangian takes the form

$$L = T - U$$

The Euler-Lagrange equations of motions for the robot are given by:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = Q_i \qquad i = 1, 2, \ldots, n$$

where $q = (\theta, \phi, \psi)$ are the generalized coordinates.

Mathematical Modelling - State Equations of the System

On solving the Euler-Lagrange equations, a non-linear model of the system is obtained. On linearizing the model about the equilibrium point($\psi = 0$) and neglecting second order terms like $\dot{\psi}^2$ and $\dot{\phi}^2$, we obtain:

$$\left[(2m+M)R^2 + 2J_w + 2n^2 J_m\right]\ddot{\theta} + \left(MLR - 2n^2 J_m\right)\ddot{\psi} = F_\theta$$

$$\left(MLR - 2n^2 J_m\right)\ddot{\theta} + \left(ML^2 + J_\psi + 2n^2 J_m\right)\ddot{\psi} - MgL\psi = F_\psi$$

$$\left[\frac{1}{2}mW^2 + J_\phi + \frac{W^2}{2R^2}\left(J_w + n^2 J_m\right)\right]\ddot{\phi} = F_\phi$$

Mathematical Modelling - State Space Representation

Here, we consider x_1, x_2 as states and u as input and thus the state space representation of the linearized model is of the form:

$$\dot{\mathbf{x_1}} = A_1\mathbf{x_1} + B_1\mathbf{u}$$
$$\dot{\mathbf{x_2}} = A_2\mathbf{x_2} + B_2\mathbf{u}$$

where,

$$\mathbf{x_1} = [\theta, \psi, \dot{\theta}, \dot{\psi}]^T, \mathbf{x_2} = [\phi, \dot{\phi}]^T, \mathbf{u} = [v_l, v_r]^T$$

Controller Design

A Servo (PID type) controller is employed to track the reference signal. An integral gain is inserted into the feedback loop in order to regulate out steady state errors.

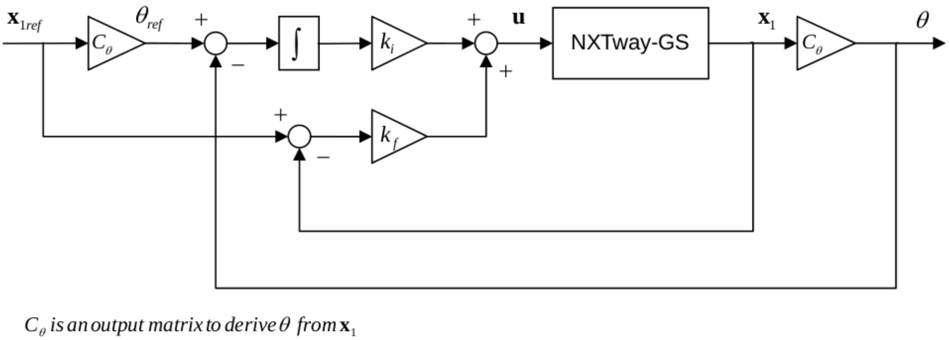


Figure : Servo Controller Block diagram

Controller Design

Additionally,

- P control is used for wheel synchronization when moving straight. This is required since two DC motors don't move at the same speed for the same voltage.
- Rotation is achieved by giving higher power to the left motor

Simulink Model - NXTway-GS

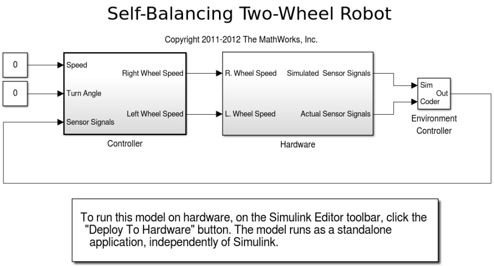


Figure : Simplified Simulink Model of NXTway-GS

Demonstration

Interesting questions

Some questions to ponder:

- Comment on the advantages of the given state feedback controller over a PID controller.
- Comment on effect of wheel radius on the stability of the inverted pendulum.

Improvements

There are a number of ways that this experiment can be extended. A few of them are listed below:

- Remote control via Bluetooth
- Dynamically changing the loop gains using feedback.
- Flip up and stabilize using switched control

References

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Two wheeled balancing LEGO robot

Thank You!