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)
4. Remote Control via Bluetooth

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

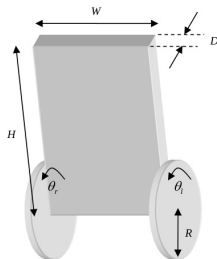# Mathematical Modelling - Diagram

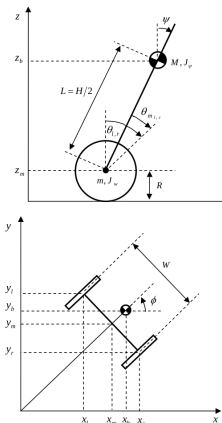Figure : Two-wheeled Inverted Pendulum

Figure : Side and plane view of two-wheeled inverted pendulum

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:

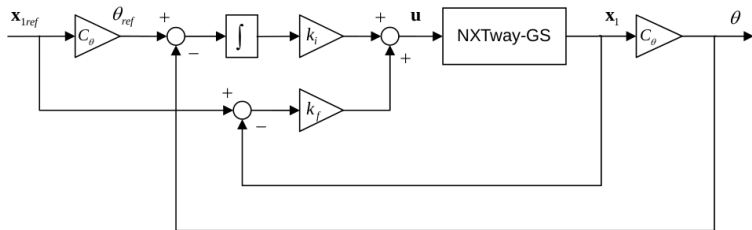$$\dot{\mathbf{x}_1} = A_1 \mathbf{x_1} + B_1 \mathbf{u}$$
$$\dot{\mathbf{x}_2} = A_2 \mathbf{x_2} + B_2 \mathbf{u}$$

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.

C_θ is an output matrix to derive θ from $\mathbf{x}_1$

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 a given voltage.

- Rotation is achieved by giving higher power to the left motor

- Remote controlled via Bluetooth by altering the $\dot{\theta}$ reference for speed and rotation is achieved as explained above.

Simulink Model - NXTway-GS
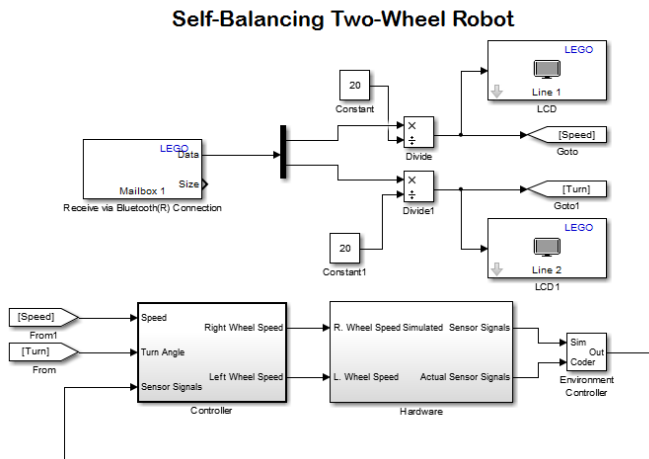
Figure : Simplified Simulink Model of NXTway-GS

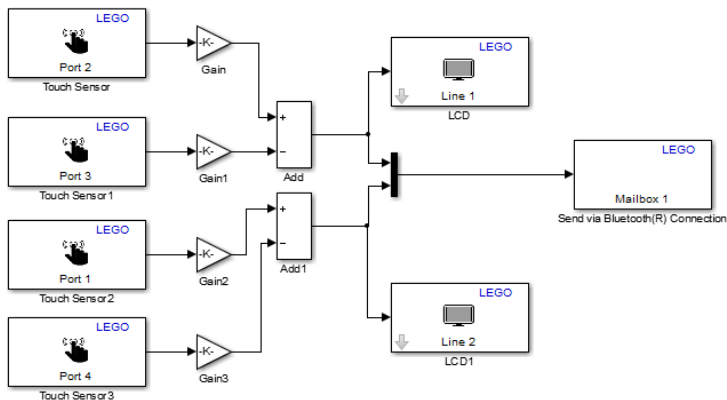# Simulink Model - Remote

Figure : Simplified Simulink Model of Remote

Demonstration

References

📄 Yorihisa Yamamoto (2008)
NXTway-GS Model-Based Design
Control of self-balancing two-wheeled robot built with LEGO Mindstorms NXT.

📄 MathWorks Simulink
LEGO Mindstorms NXT Support from Simulink
http://www.mathworks.in/hardware-support/lego-mindstorms-simulink.html

📄 Gyro Sensor (NGY1044)
HiTechnic
www.hitechnic.com/cgi-bin/commerce.cgi?preadd=action&key=NGY1044

📄 Jonsson Per, Piltan Ali, Rosen Olov
Two wheeled balancing LEGO robot

Thank You!