# Motion Control of NXTway(LEGO Segway)

## ー Control Experiments with LEGO Mindstorms NXT ー

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# 1. Introduction

# 1. Introduction

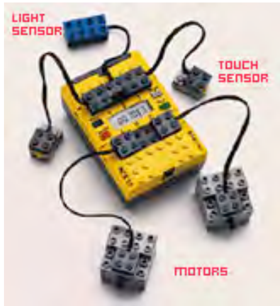
- LEGO Mindstorms

Integrated Development Environment for Educational Robot

Programming Environment(GUI)

LEGO Technic Parts

Controller, Actuators, and Sensors



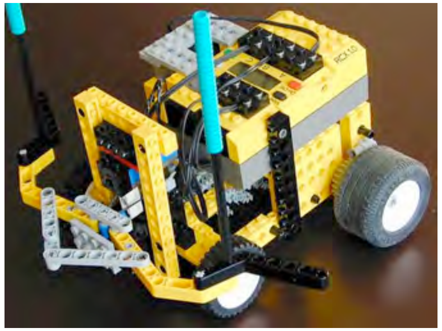

RCX(1998-)

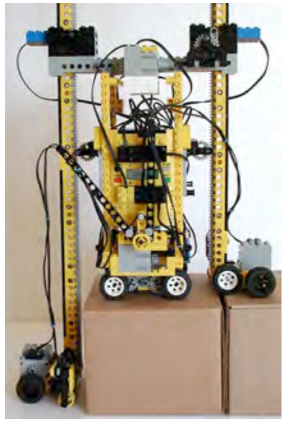
NXT(2006-)

Educational Robots

# 1. Introduction

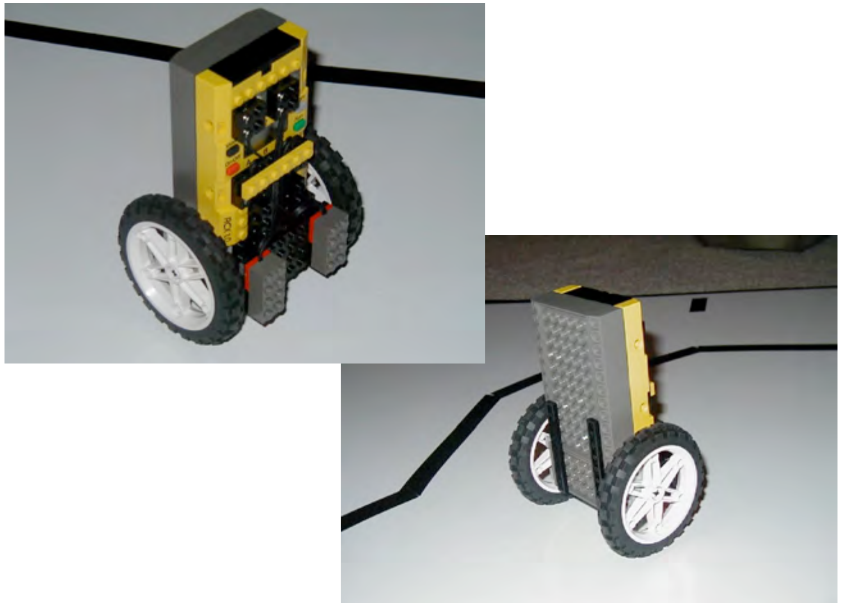
- Robots build with LEGO Mindstorms



- Steve Hassenplug's Legway

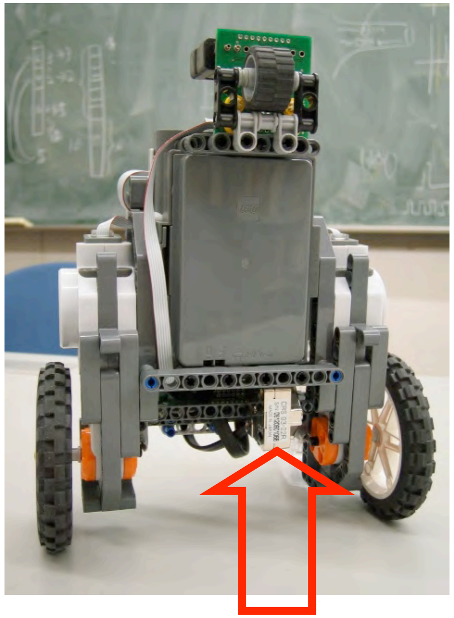
  The most famous self-balancing robot built with LEGO Mindstorms

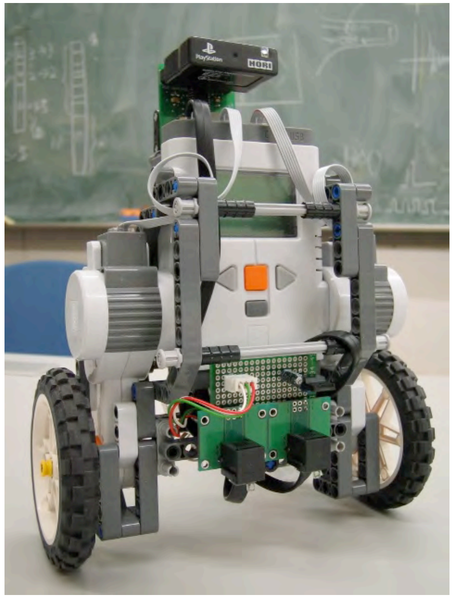


Dean Kamen's Segway

# 1. Introduction

- NXTway-G (LEGO Segway with Gyro Sensor)





Gyro Sensor

Modeling
Model-based Controller Design
Numerical Simulation
Implementation of Control System
Control Experiment

Discuss the possibility of LEGO Mindstorms NXT
as the platform for Control Experiment

# 2. LEGO Mindstorms NXT

# 2. LEGO Mindstorms NXT

- Overview

LEGO Mindstorms NXT

NXT Block(CPU), Servo Motors, and Sensors

+

LEGO Technic Parts

Educational Robots

# 2. LEGO Mindstorms NXT

- NXT Block

  Processors
  - Main processor: Atmel 32-bit ARM processor, AT91SAM7S256
    256 KB FLASH, 64 KB RAM, 48 MHz
  - Co-processor: Atmel 8-bit AVR processor, ATmega48
    4 KB FLASH, 512 Byte RAM, 8 MHz

  Interface
  - 4 input ports 6-wire interface
    supporting digital and analog interface
  - 3 output ports 6-wire interface
    supporting input from encoders
  - 4 button user-interface Rubber buttons


  Communication
  - Bluetooth wireless communication
    CSR BlueCoreTM 4 v2.0 +EDR System
  - USB 2.0 communication Full speed port
    12 Mbit/s

# 2. LEGO Mindstorms NXT

- Programming Environment

NXT-G(GUI), RoboLab(GUI), RobotC(C), NXC(C), leJOS(Java), ….

## RobotC

IDE(Integrated Development Environment) for LEGO Mindstorms NXT
developed by Carnegie Mellon University Robotics Academy

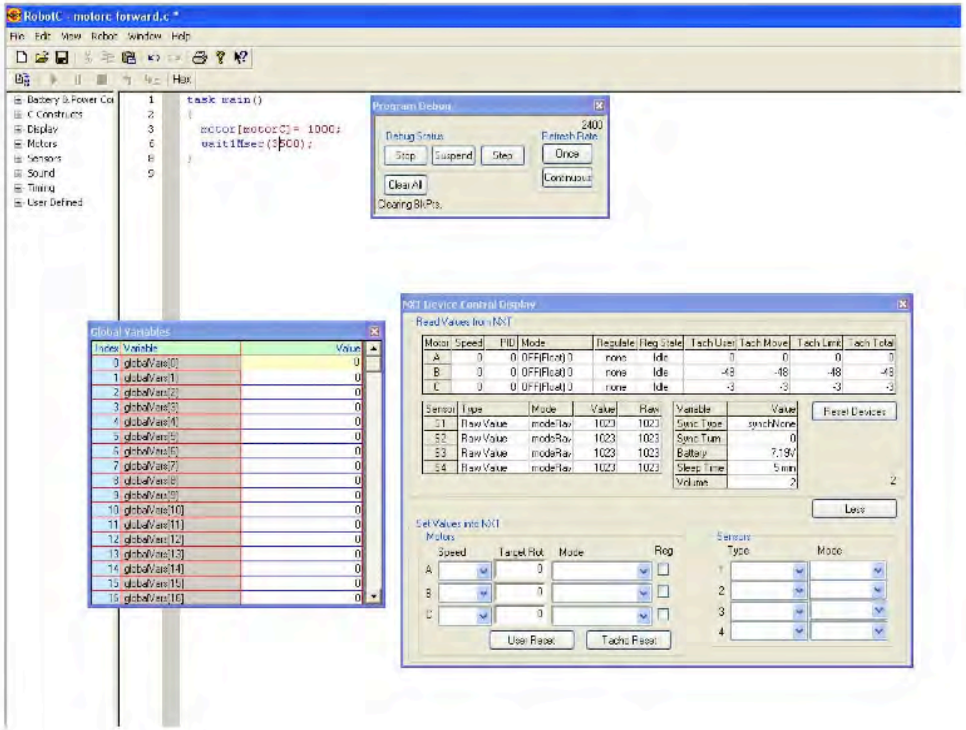
### Feature

C Language

Useful Debugger

Floating-Point Calculation

Timer Resolution : 1(ms)



# 3. NXTway-G

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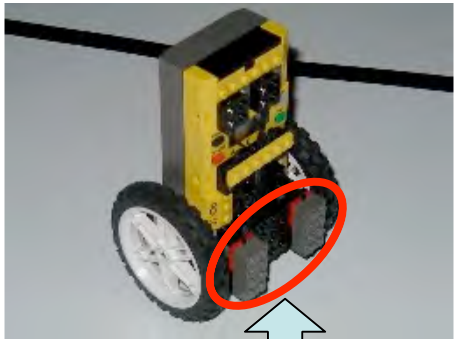
- Legway and NXTway

Dean Kamen's Segway

LEGO Mindstorms (NXT)

Steve Hassenplug's Legway



Philippe Hurbain's NXTway

Measurement of light sensor

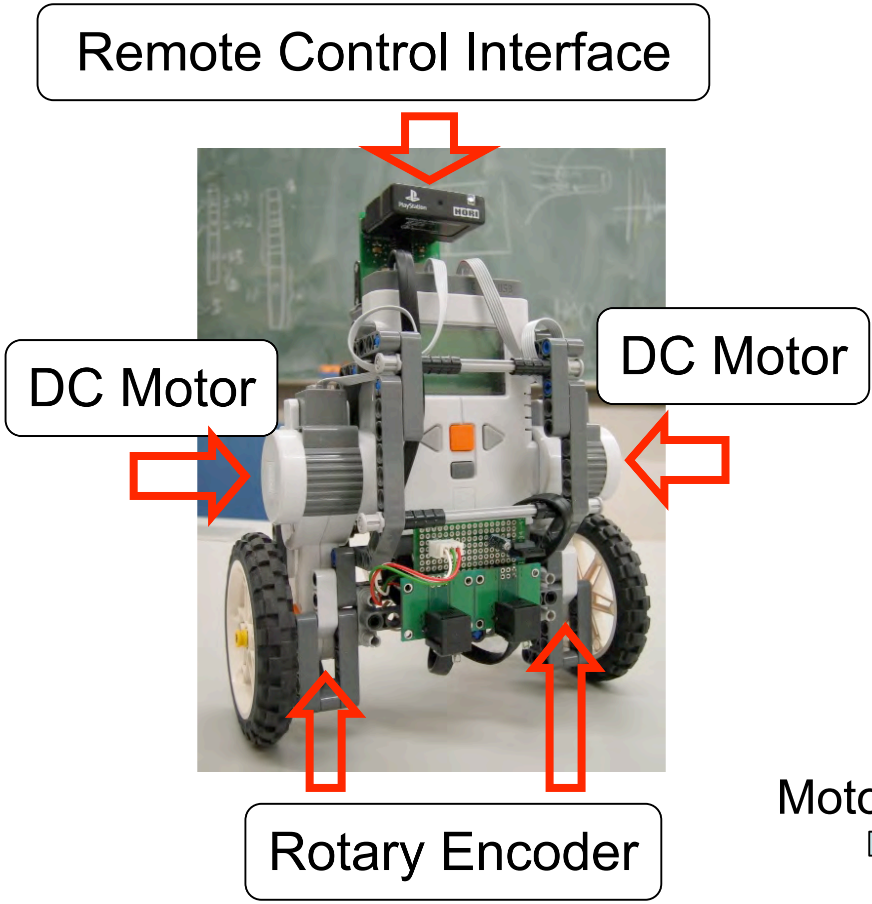
⇨ Body's rotation angle

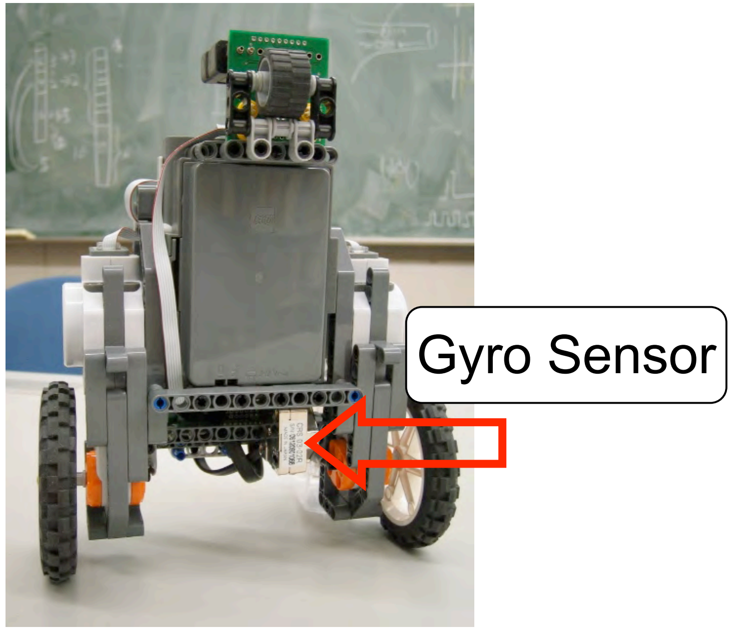
Information on wheel's rotation angle is NOT used

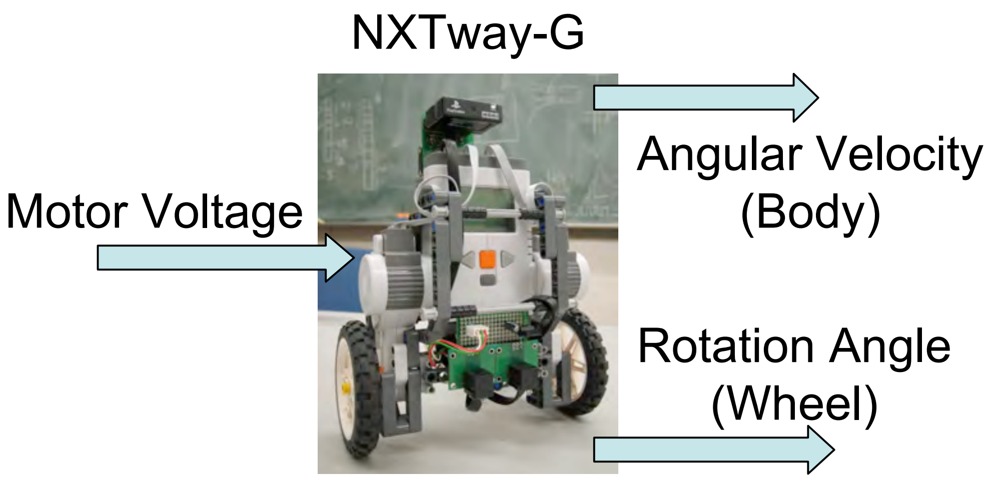
⇨ Internal Stability is NOT achieved

# 3. NXTway-G

- NXTway-G

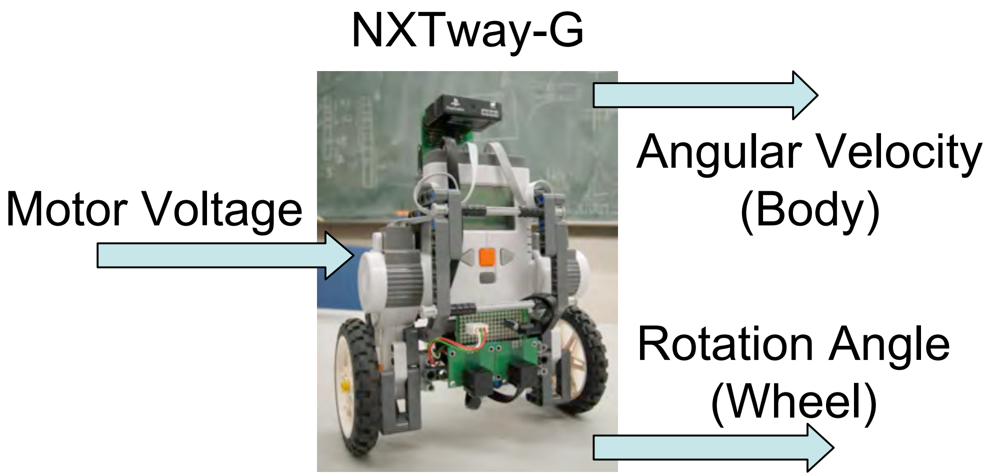


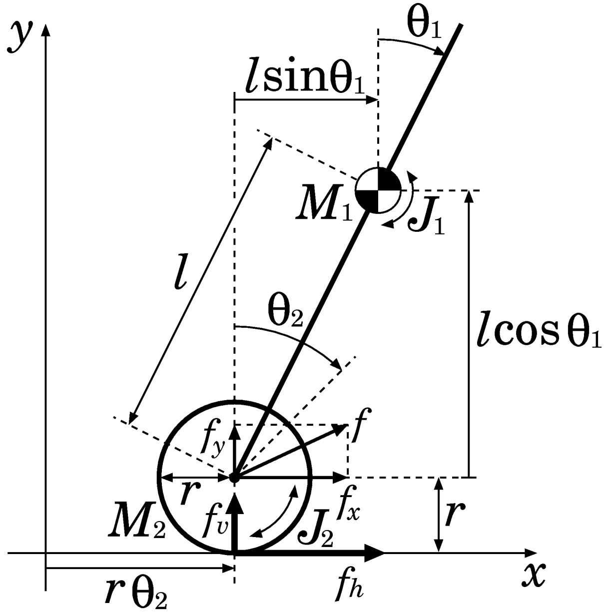



# 3. NXTway-G

- Dynamics of NXTway-G




- Linearized Model around Equilibrium Point

State Variable

$$\theta = \begin{bmatrix} \theta_1 \\ \theta_2 \end{bmatrix}, \quad \omega = \begin{bmatrix} \omega_1 \\ \omega_2 \end{bmatrix}$$

Equilibrium Point

$$\theta = 0, \quad \omega = 0$$

State Equation

$$\frac{d}{dt}\begin{bmatrix} \omega \\ \theta \end{bmatrix} = \begin{bmatrix} -J_l^{-1}D_l & -J_l^{-1}K_l \\ I & 0 \end{bmatrix} \begin{bmatrix} \omega \\ \theta \end{bmatrix} + \begin{bmatrix} J_l^{-1}E_l \\ 0 \end{bmatrix} e_m$$

# 4. Motion Control of NXTway-G

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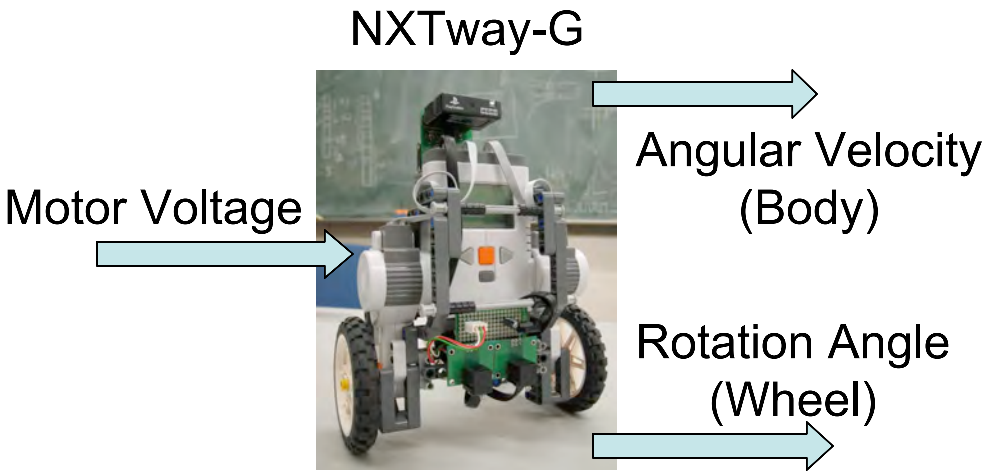
- Structure of Control System

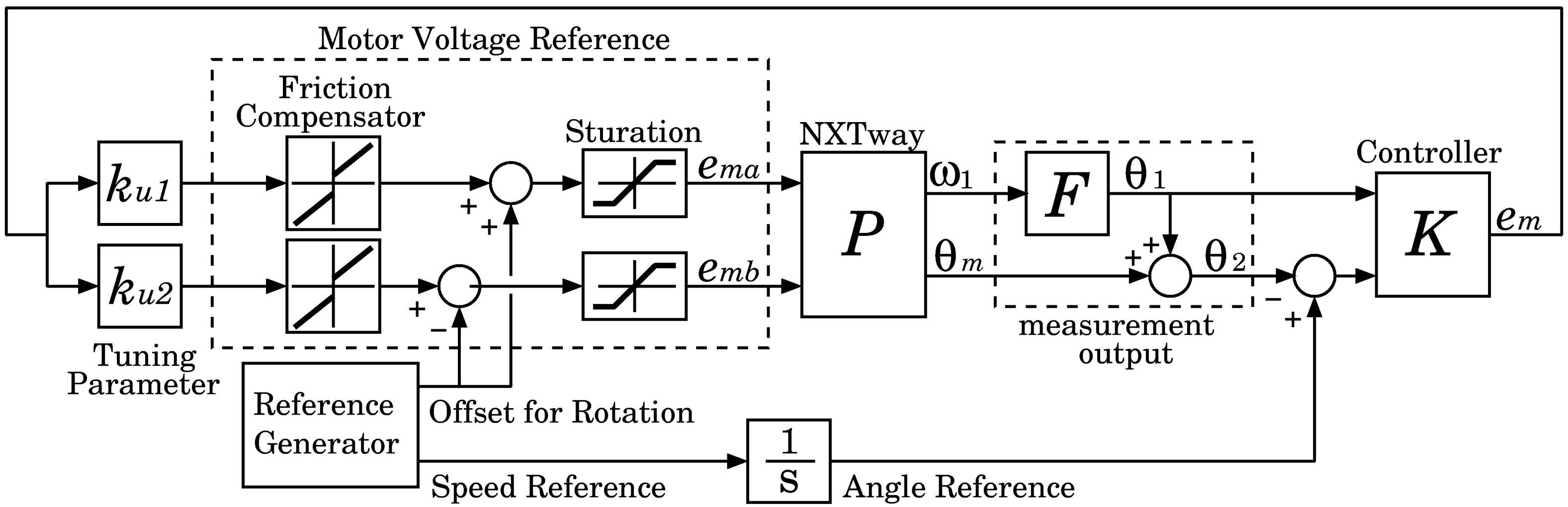



Control Objective

Internal Stabilization
Position Tracking

Control System

Reference Generator
Friction Compensator
Stabilization & Tracking Controller
Tuning Parameter



# 4. Motion Control of NXTway-G

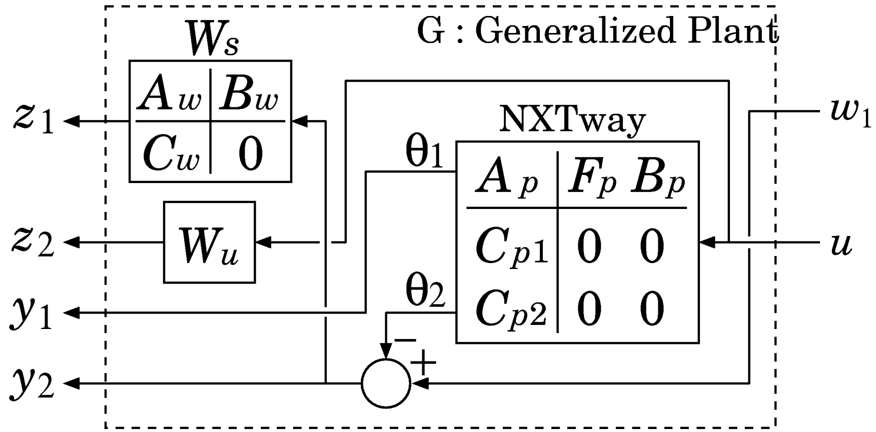
- Stabilization & Tracking Controller

**Tracking Performance**

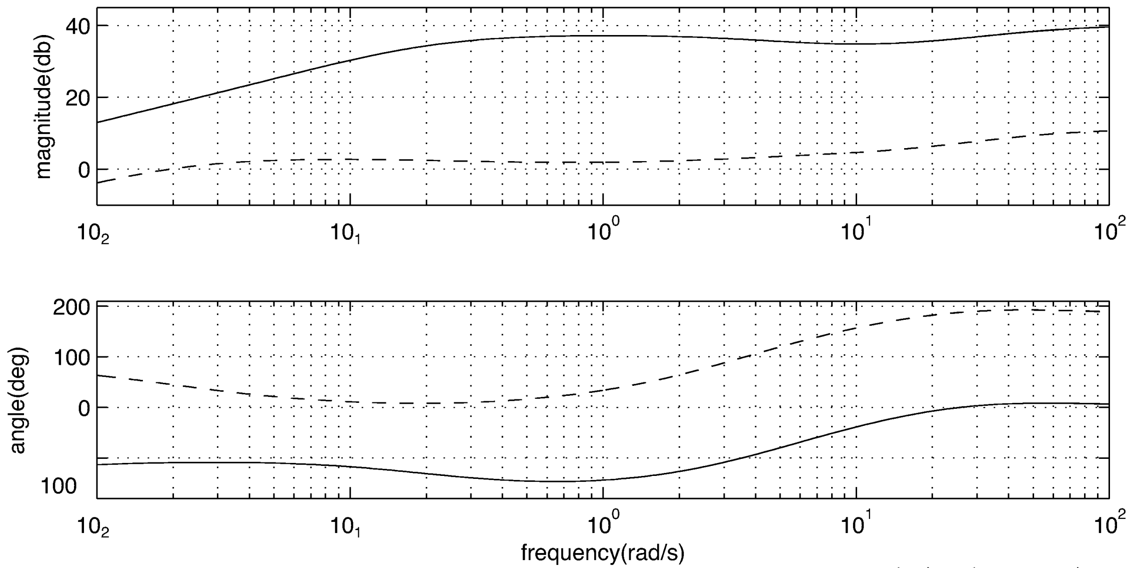
$$\|G_{z_1/w_1}\|_\infty < 1$$

**Sensitivity of Control Input**

$$\|G_{z_2/w_1}\|_\infty < 1$$




$$K(s) = \begin{bmatrix} K_1(s) & K_2(s) \end{bmatrix}^T$$

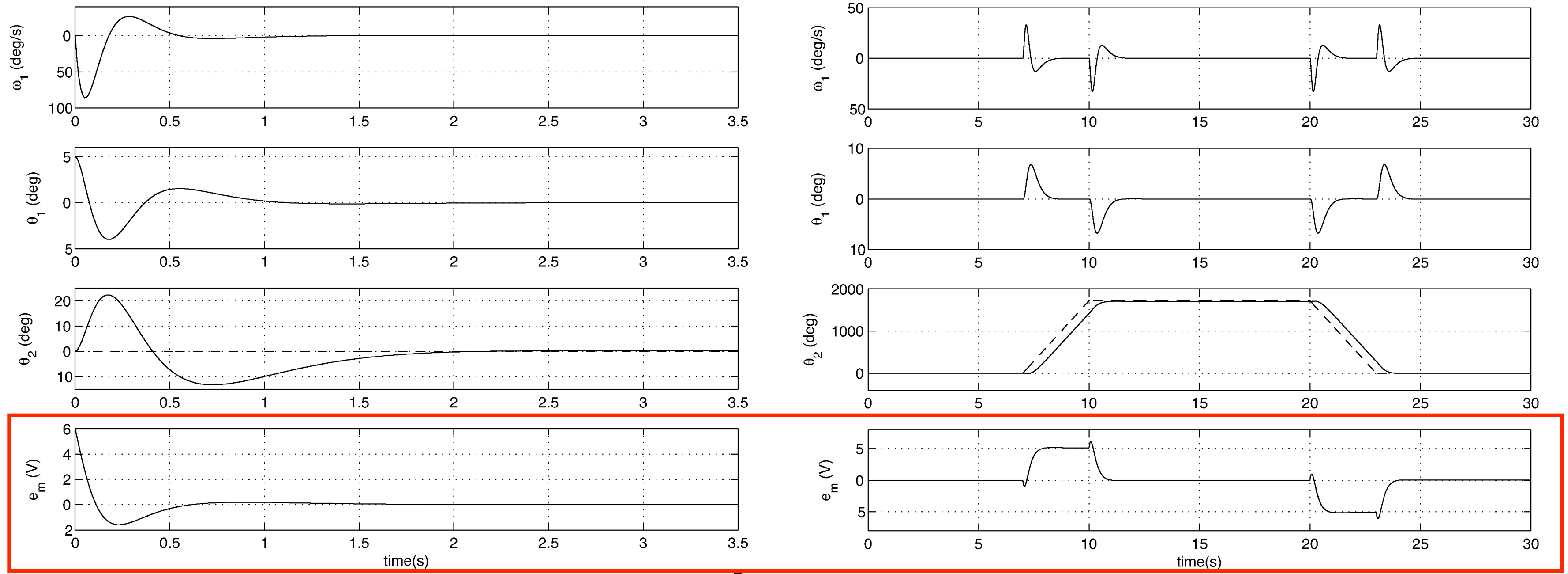



$K_1(s)$ (solid), $K_2(s)$ (dashed)

# 4. Motion Control of NXTway-G

- Simulation Results

Internal Stability | Tracking




$$-8(\mathrm{V}) \leq e_m \text{ (Motor Voltage) } \leq 8(\mathrm{V})$$

# 4. Motion Control of NXTway-G

- Experimental Results

Internal Stability

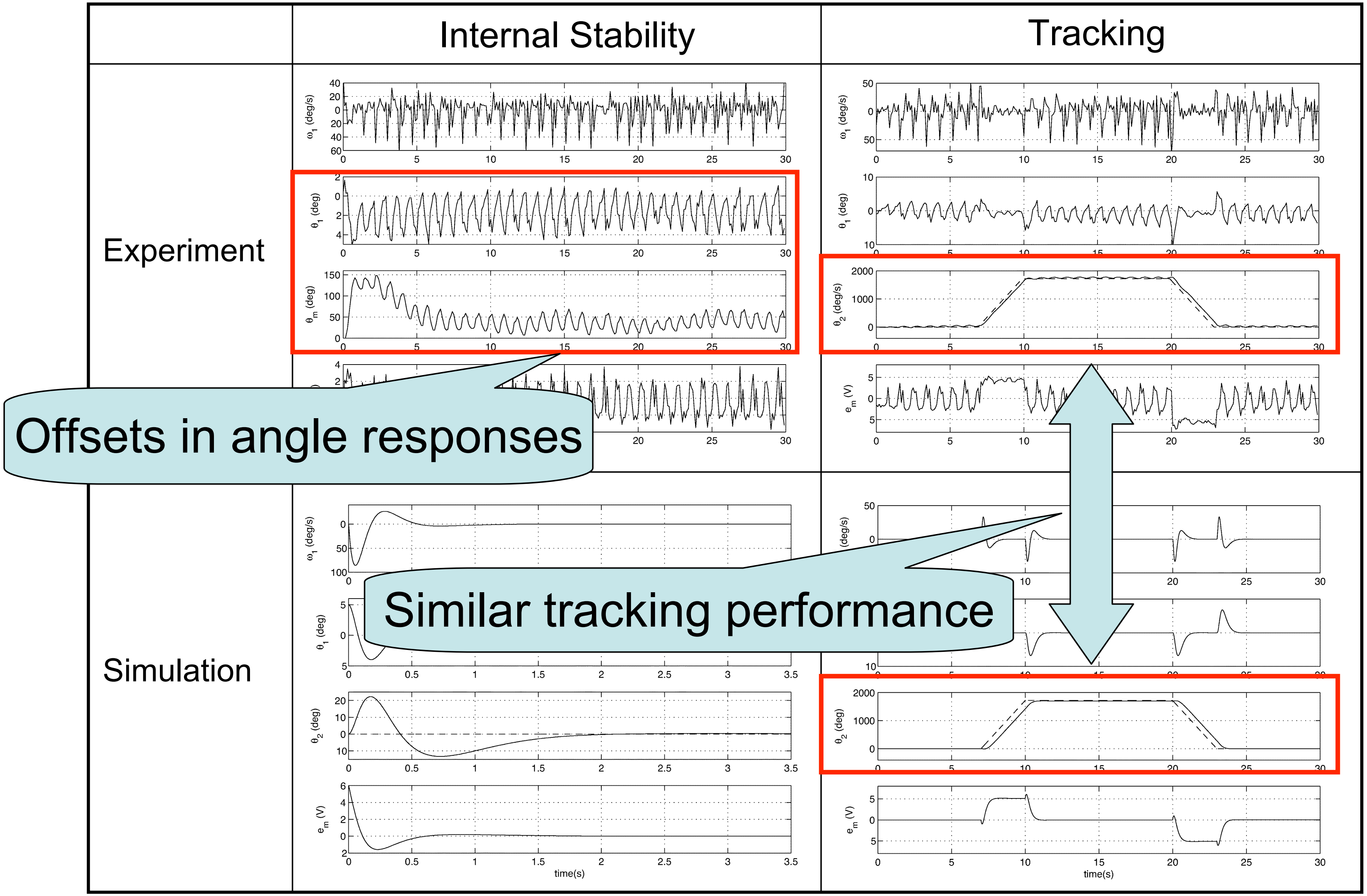
Tracking

Slope

Demonstration

# 4. Motion Control of NXTway-G

- Experimental Results



# 5. Conclusion

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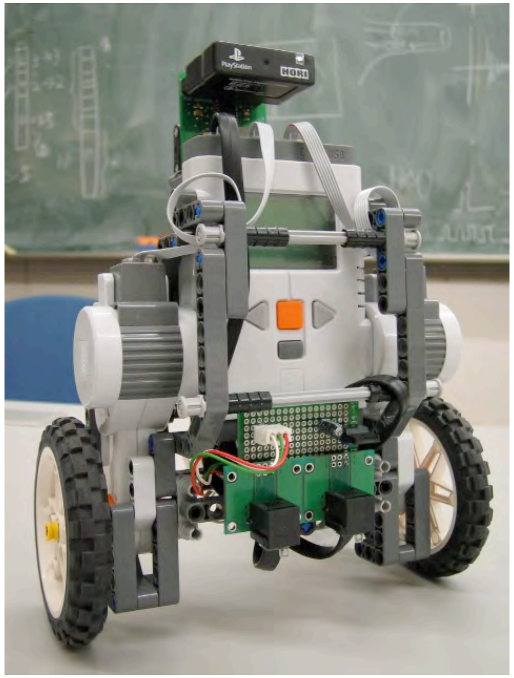
- In this presentation, we discussed …

  Design and Construction of NXTway-G
  NXTway-G's Motion Control System

- From the experimental results, we see …

  The potential of LEGO Mindstorms NXT for the platform of control experiments
  The power of model-based control theory

- Next Project



NXT Motorbike