ASIAN INSTITUTE OF TECHNOLOGY

Advanced Control of Robotics and Mechatronics System

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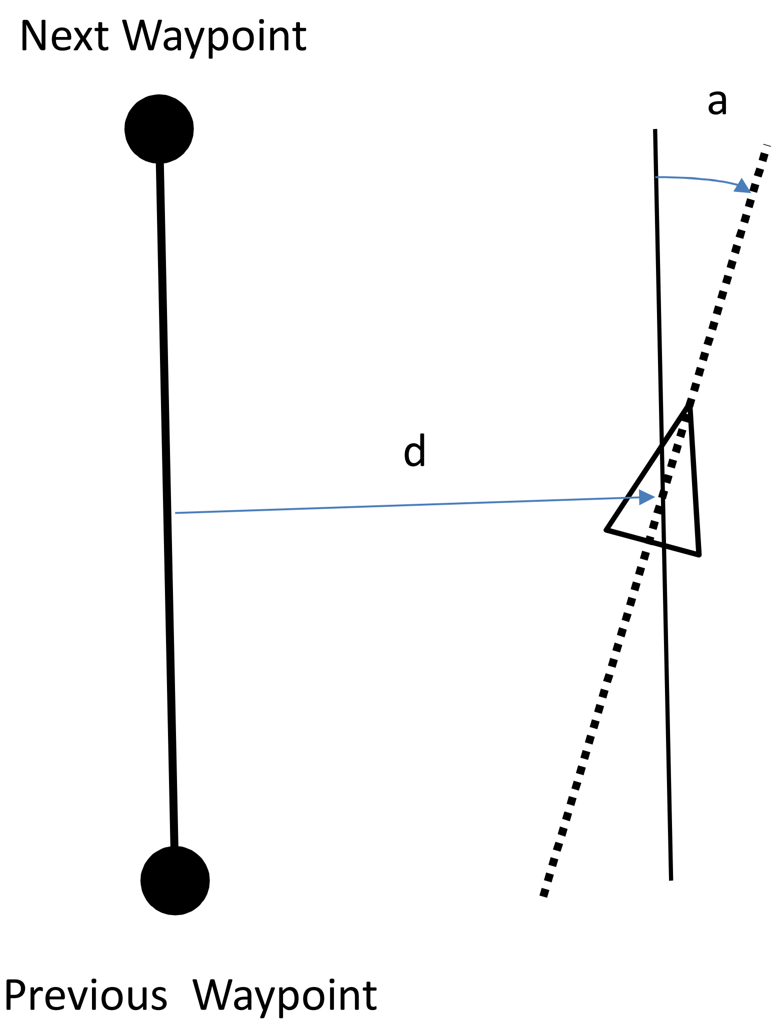
Selected Robotics and Mechatronics Systems

- Intelligent Vehicles
- Unstable Vehicles/Robots
- Haptics or Master-Slave Robots/Machines
- Exoskeleton Robots
- Inverted Pendulums
- AGV, LGV
- Artificial Intelligence
- Robo-Animal
- Earth Observation Satellite

Intelligent Vehicles

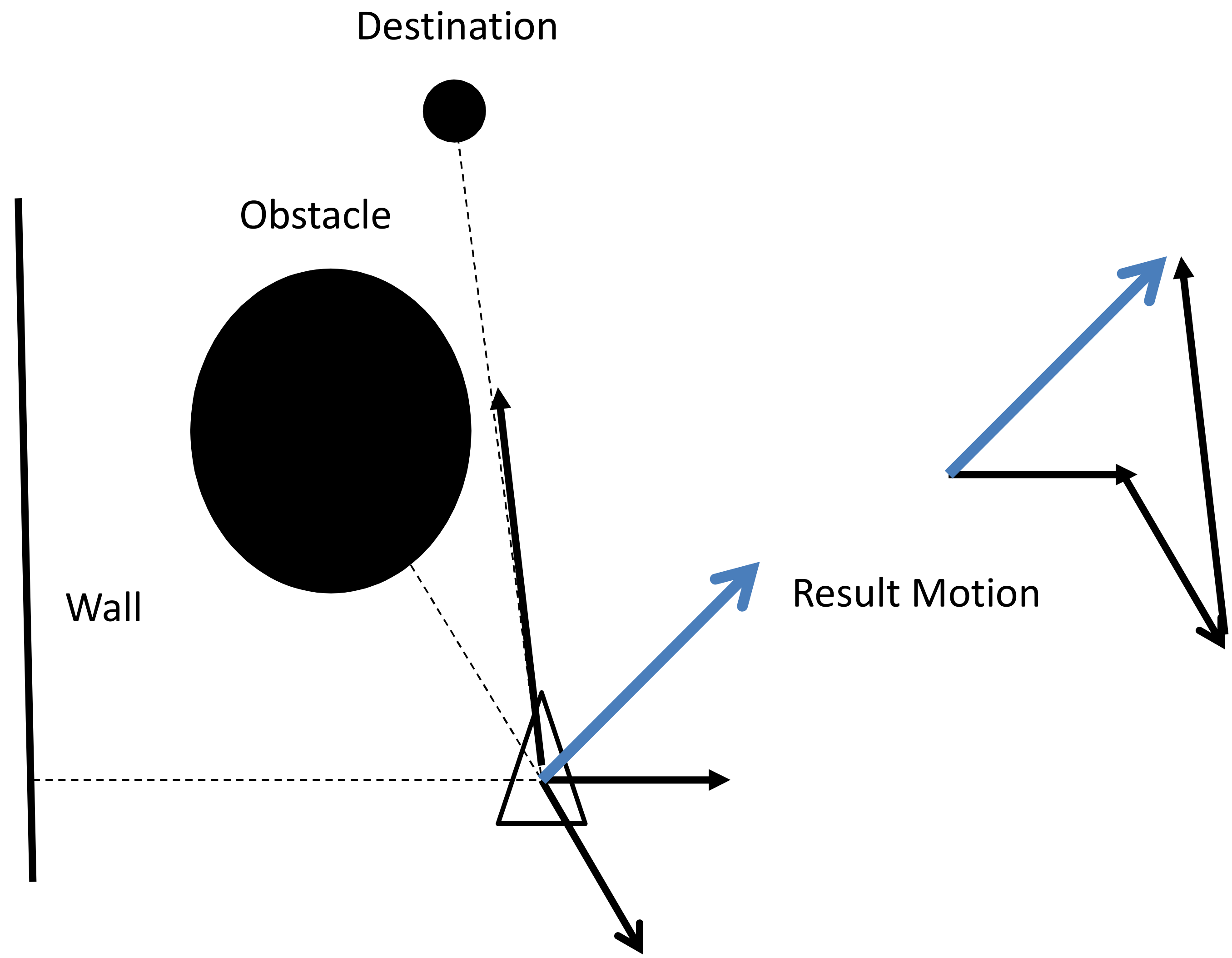
Unmanned Car Video

Waypoint Tracking



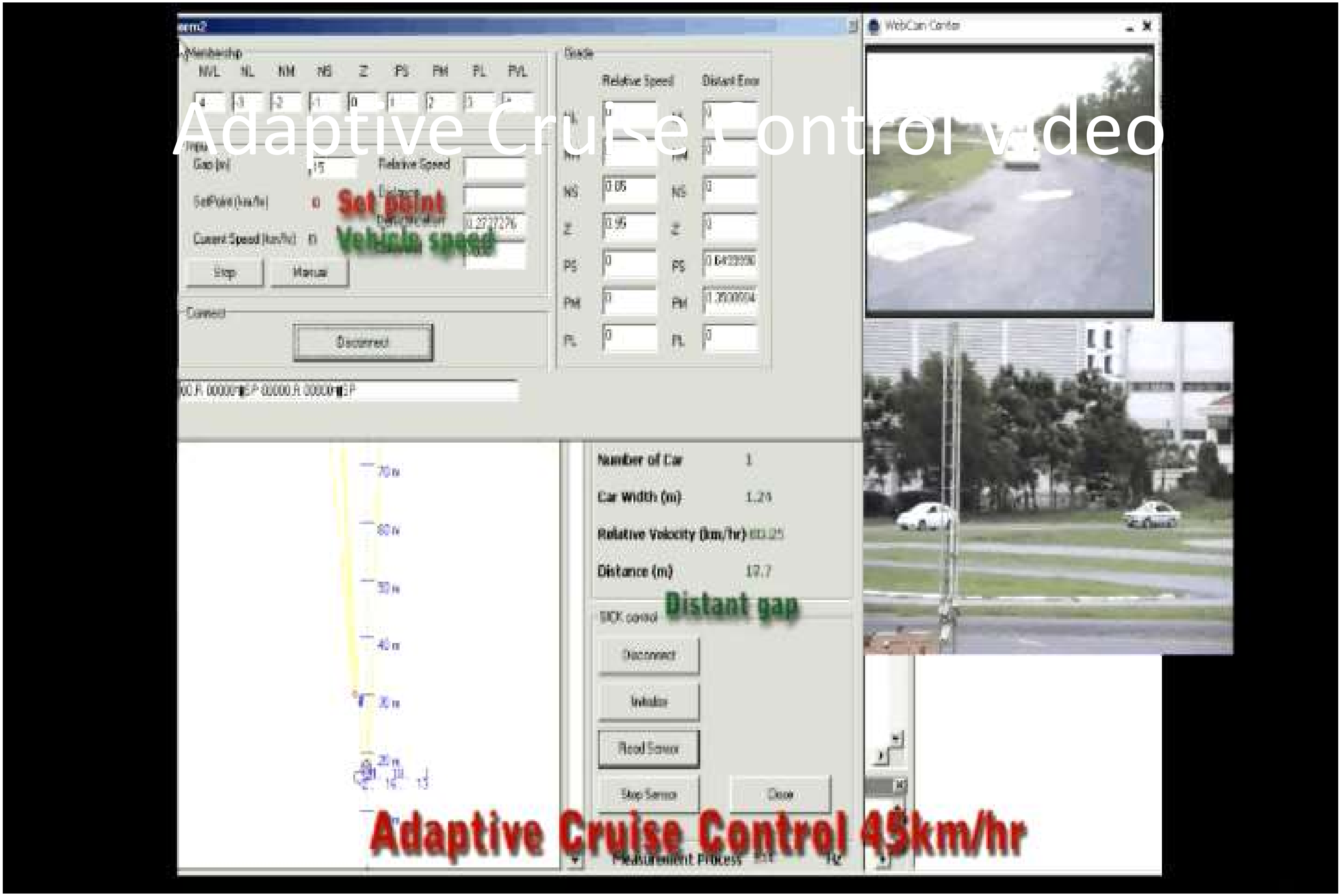
$$Steering = K_{dis\_P}(d) + K_{dis\_D}(\dot{d}) + K_{head\_P}(a) + K_{head\_d}(\dot{a})$$

Obstacle Avoidance

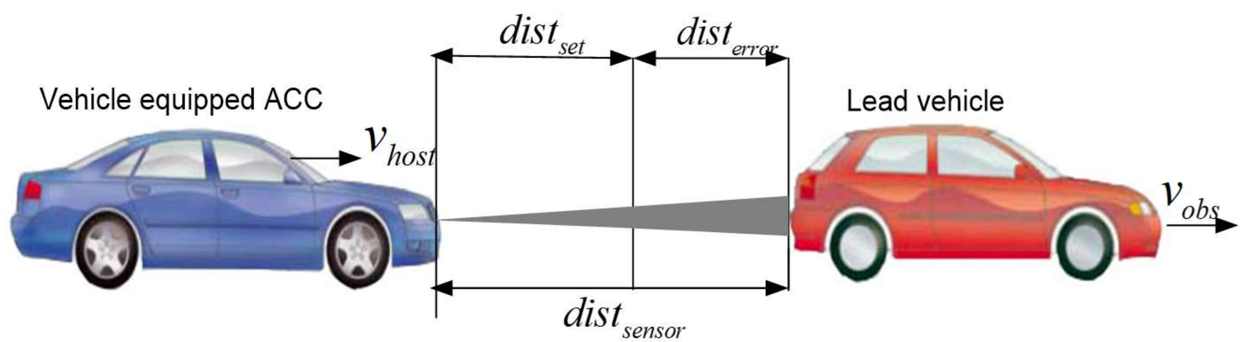


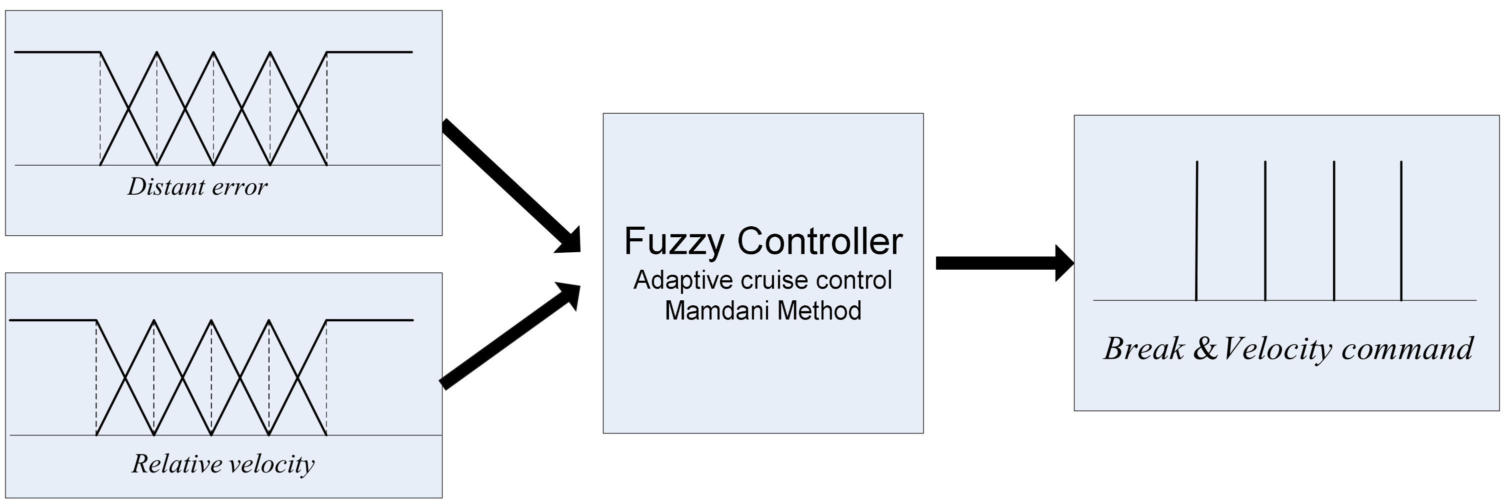
Virtual Force = Virtual Spring Force + Virtual Damping Force

Adaptive Cruise Control video

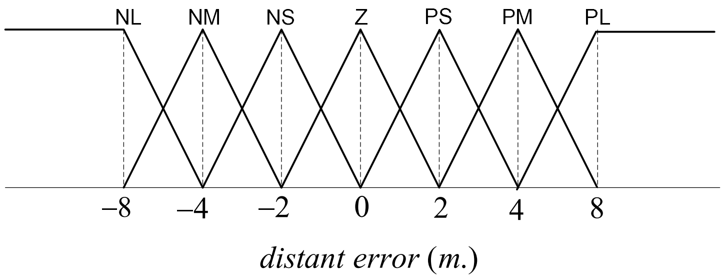


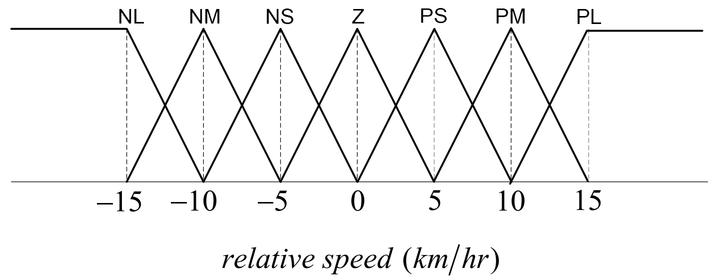
FLC based Speed Control

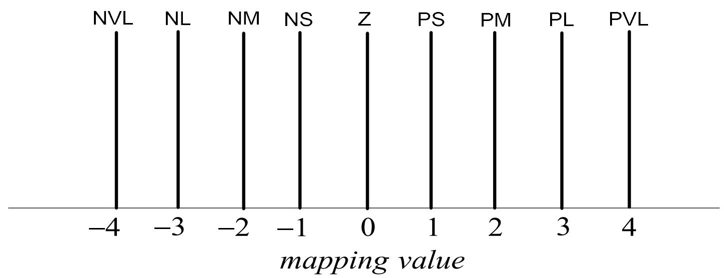




Membership Functions and Rules







	NL	NM	NS	Z	PS	PM	PL
NL	NVL	NVL	NVL	NL	NM	NS	NS
NM	NVL	NL	NM	NM	NS	NS	Z
NS	NL	NM	NS	NS	NS	Z	Z
Z	NM	NS	Z	NS	Z	PS	PS
PS	NS	Z	Z	Z	Z	PM	PL
PM	NS	Z	Z	PS	PM	PL	PVL
PL	NS	Z	Z	PS	PL	PVL	PVL

Automatic Parking Video

Flying Robot Video

Underwater Robot Video

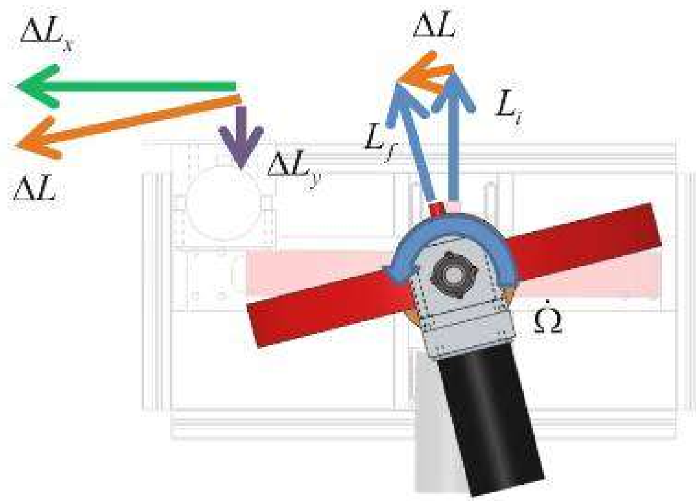
Spherical Robot Video

Pendulum-based Spherical Robot Video

Unstable Vehicles/Robots

Gyro based BicyRobo Video

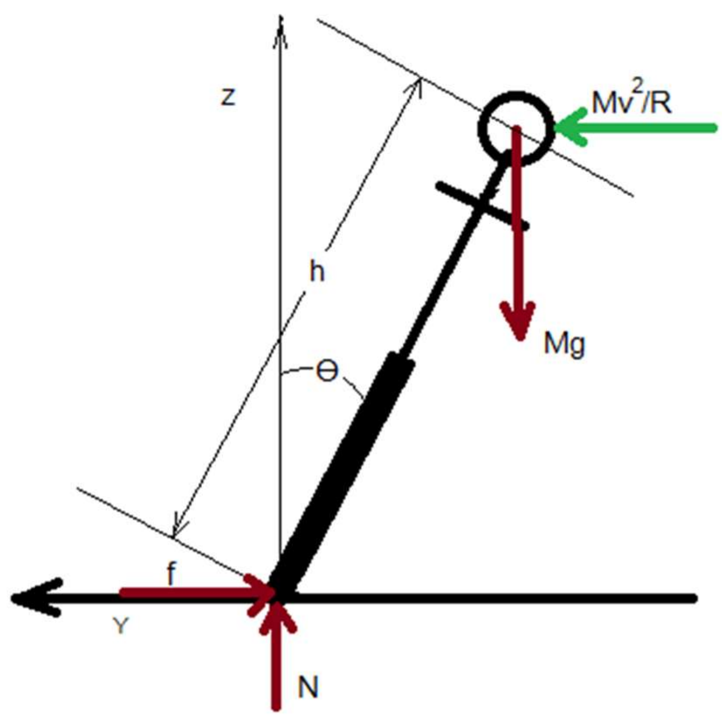
Torque from Momentum Wheel



Centrifugal Force based BicyRobo Video

Centrifugal Force based Balancing

- Centrifugal force is proportional to square of speed and inverse of radius.



Two-Wheel Balancing Robot Video

6-DOF Controlled Unicycle Video

AIT

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Haptics or Master-Slave Robots/Machines

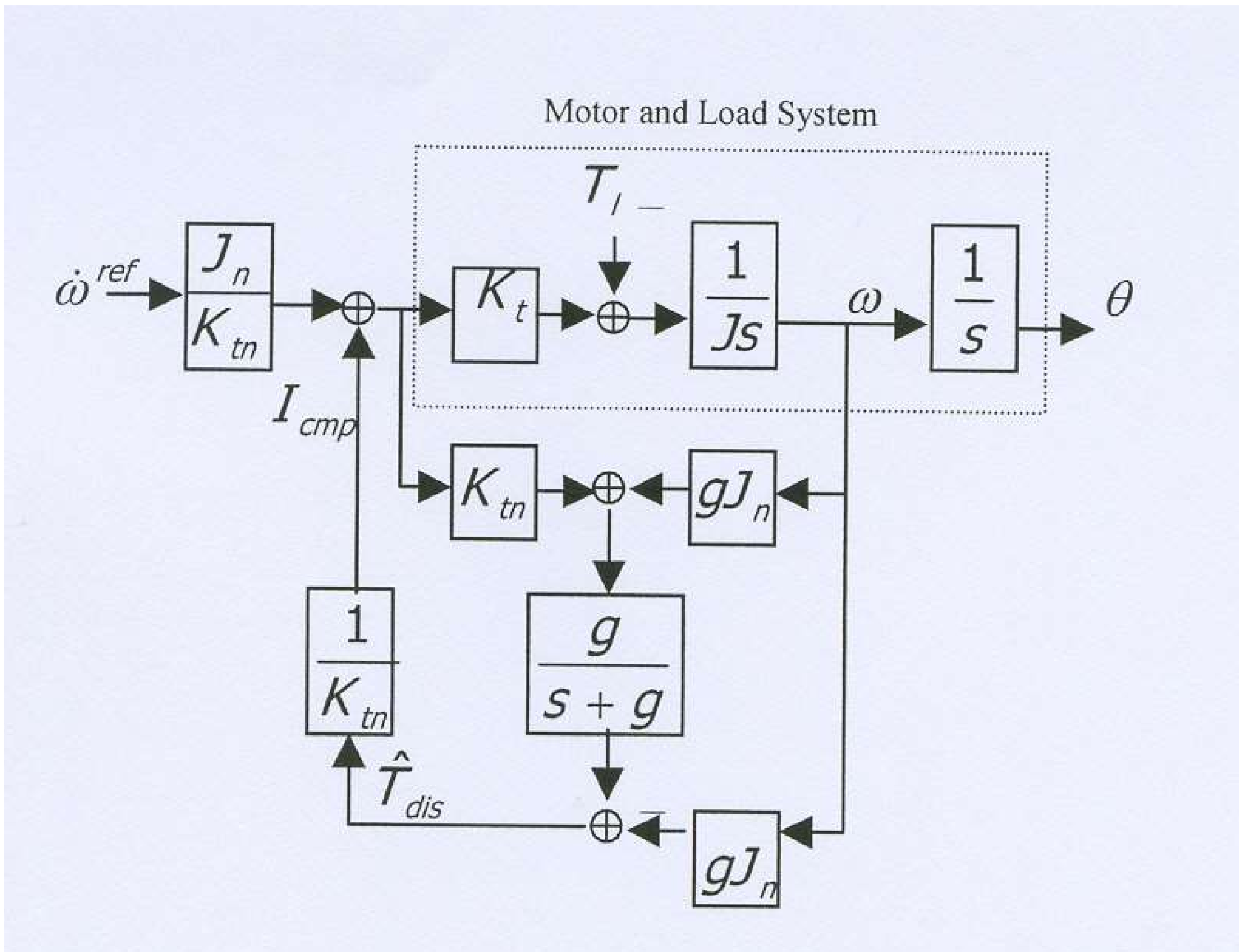
Video

Video

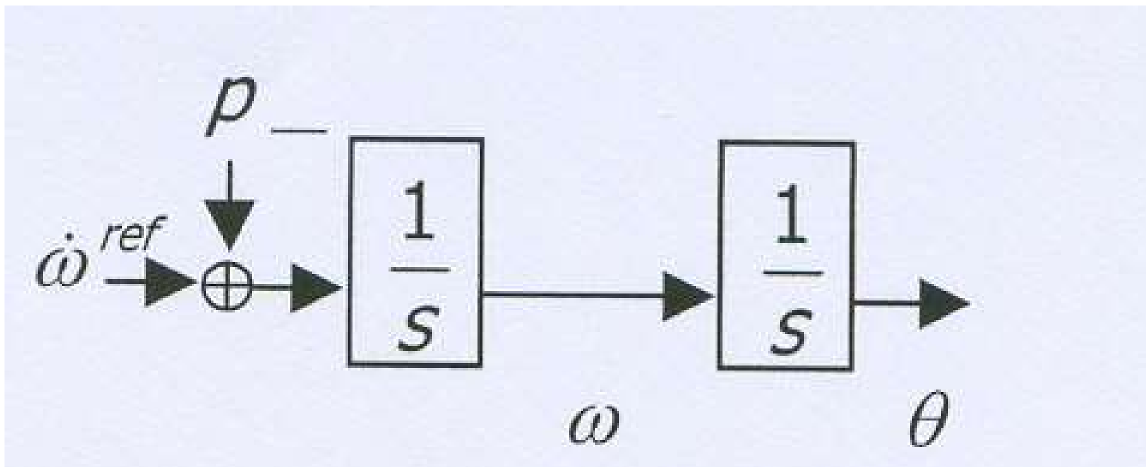
Medical Tele-Analyzer

Mode: Manual

Disturbance Observer-Based Robust Motion Control



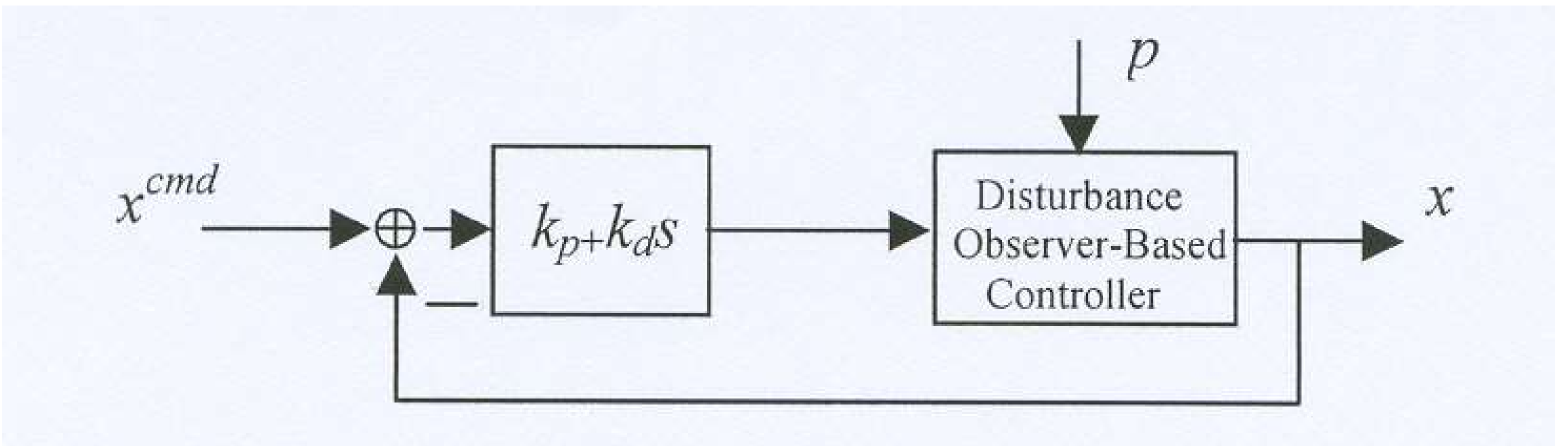
Equivalent Block Diagram of Disturbance Observer-Based Robust Motion Controller



$$p = \dot{\omega}^{ref} - \dot{\omega} = J_n^{-1} G_s T_{dis}$$

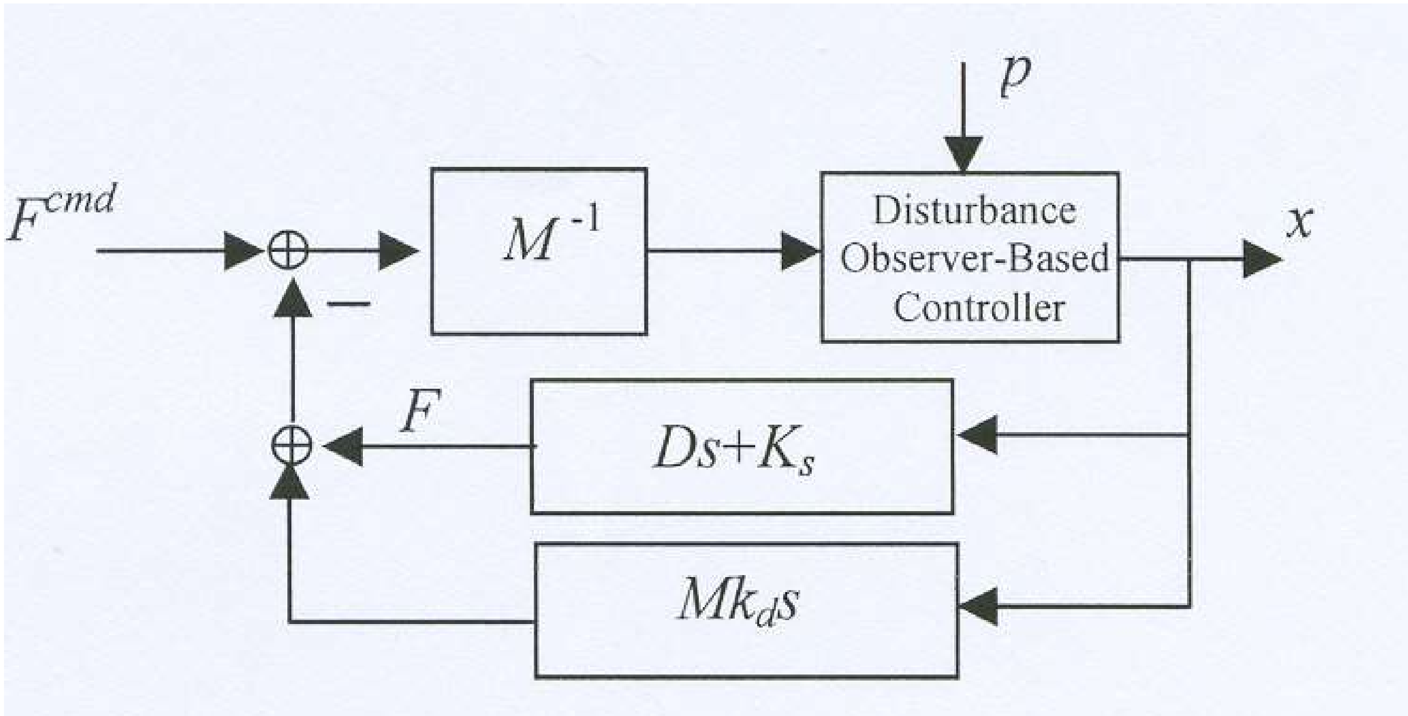
$$G_s = \frac{s}{s + g}$$

Displacement Controller



$$x = x^{cmd} - \frac{x^{cmd} s^2 + p}{s^2 + k_d s + k_p}$$

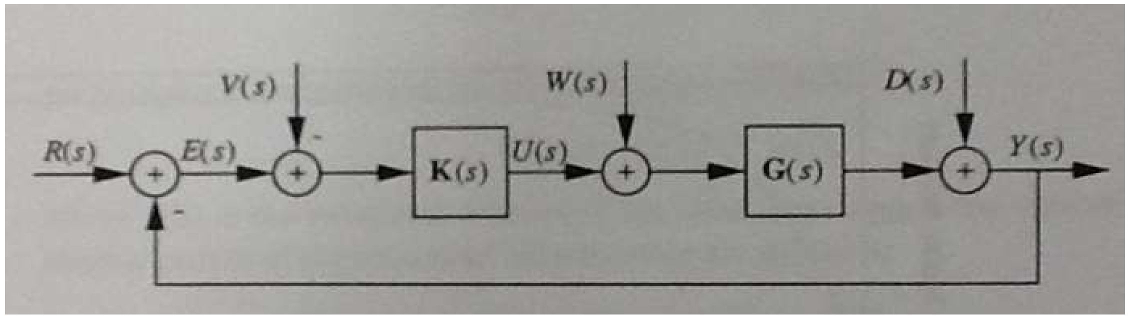
Force Controller



$$F = F^{cmd} - M(xs^2 + k_d xs + p)$$

Surgical Robot Video

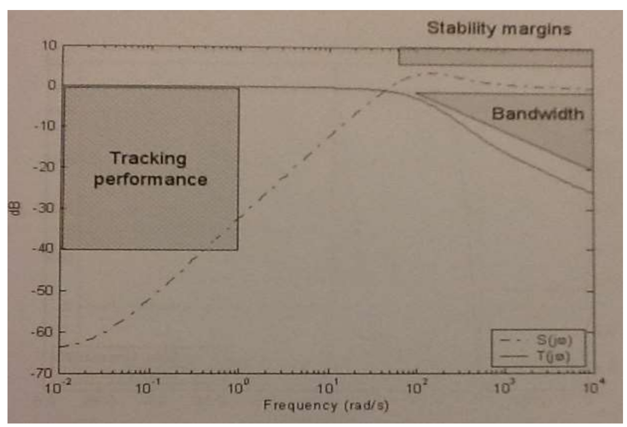
Mixed Sensitivity H-Infinity



$R(s)$ = reference input, $V(s)$ = measurement error, $W(s)$ = actuator error, $D(s)$ = output disturbance

$$E(s) = S(s)[R(s) - D(s)] + T(s)[V(s)] - S(s)G(s)[W(s)]$$

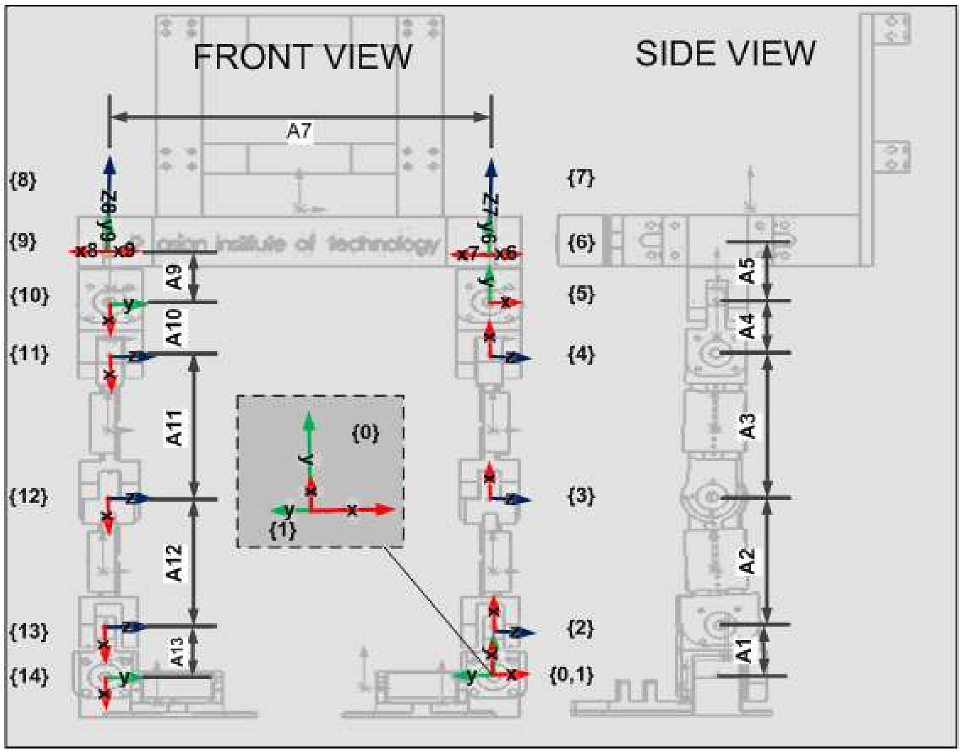
$$S(s) = \left(1 + L(s)\right)^{-1} \qquad T(s) = \left(1 + L(s)\right)^{-1} L(s) \qquad S(s) + T(s) = I$$



Exoskeleton Robots

Leg-Exoskeleton Video

Zero Moment Point (ZMP)

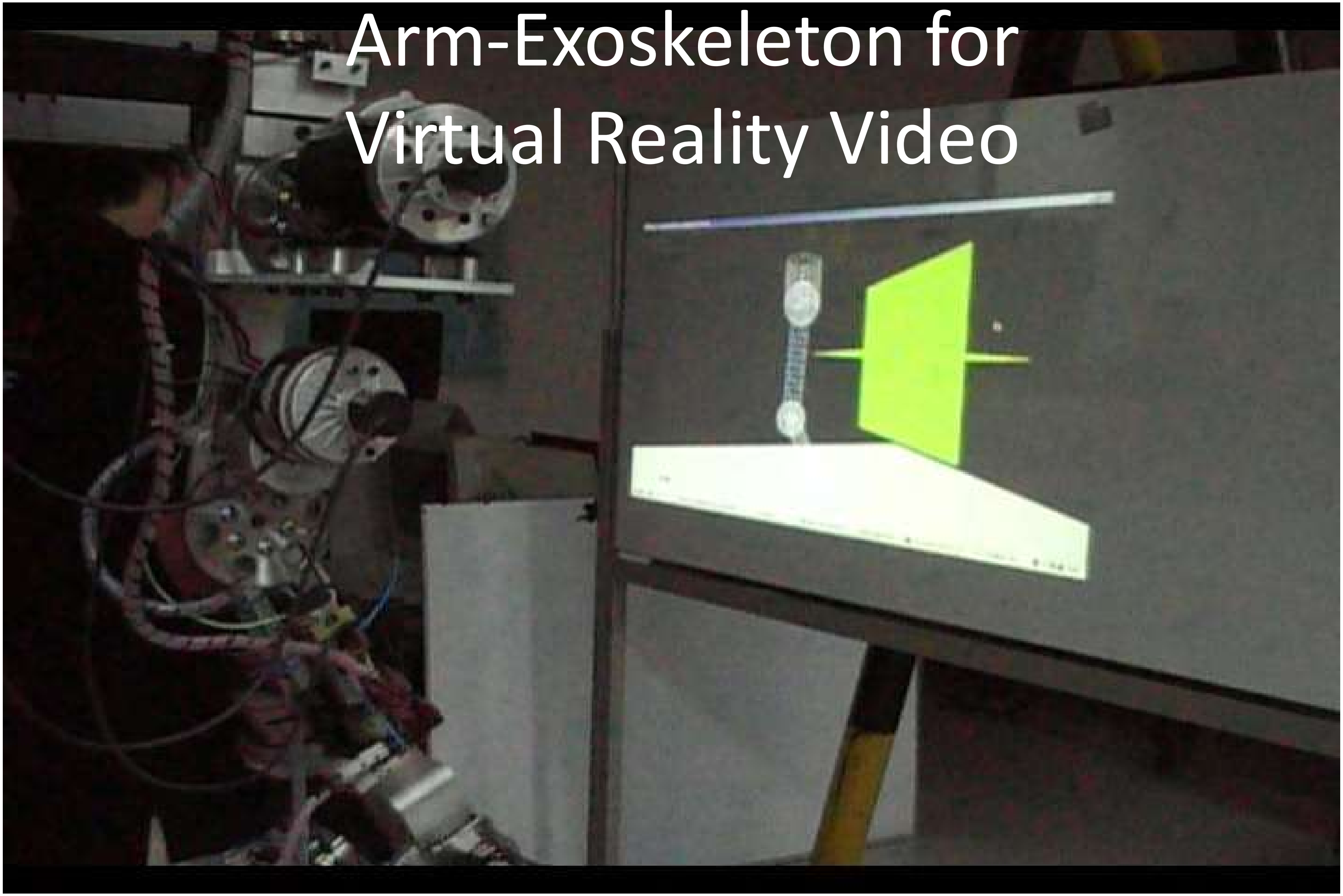


$$Z_{zmp} = \frac{\sum m_i(\ddot{y}+g)z_i - \sum m_i \ddot{z} y_i - \sum I_{ix}\ddot{\theta}_{ix}}{\sum m_i(\ddot{y}+g)}$$

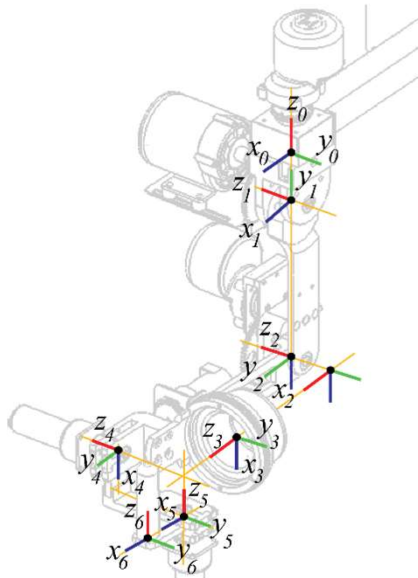
$$X_{zmp} = \frac{\sum m_i(\ddot{y}+g)x_i - \sum m_i \ddot{x} y_i - \sum I_{iz}\ddot{\theta}_{iz}}{\sum m_i(\ddot{y}+g)}$$

$$Y_{zmp} = y_{ground}$$

Arm-Exoskeleton for Virtual Reality Video



Impedance Control

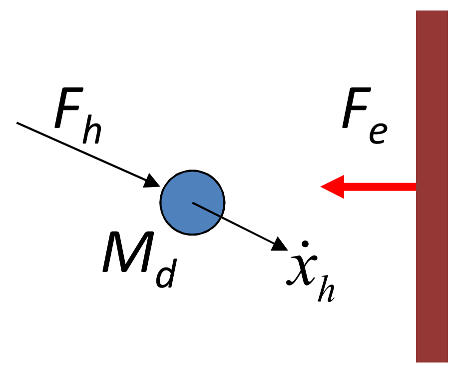


Link i	a_i (cm)	α_i (deg)	d_i (cm)	θ_i (deg)
1	0	90	-10	θ_1
2	27.0	0	0	θ_2-90
2-1	0	-90	-6.5	θ_3
3	0	0	21.8	0
3-1	0	90	8.5	θ_4
4	0	0	11	0
4-1	7.3	0	0	θ_5
4-2	0	0	0	90
5	0	-90	-12.4	0
6	8.0	0	0	θ_6

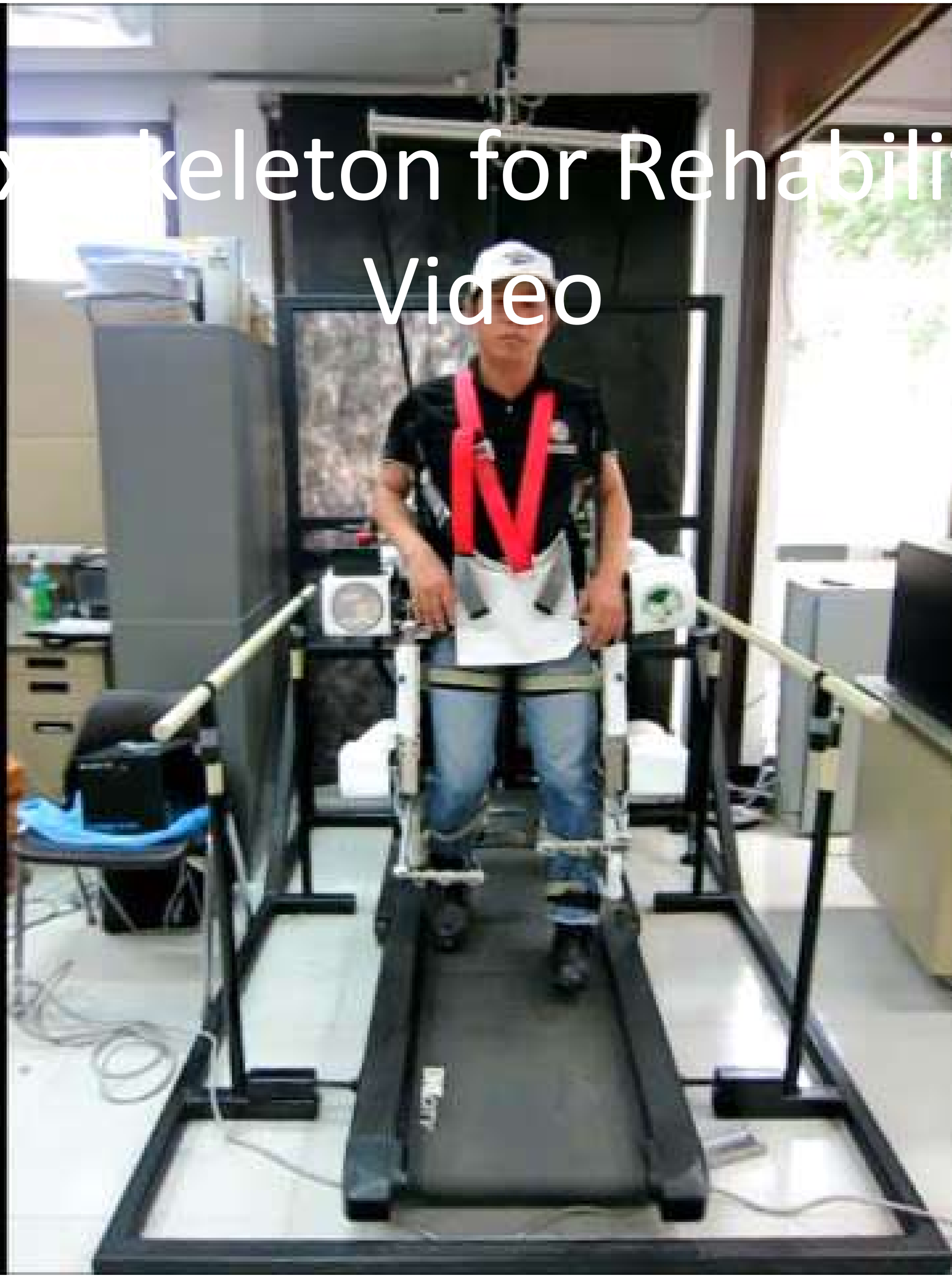
$$\boldsymbol{M}(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}} + \boldsymbol{C}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})\dot{\boldsymbol{\theta}} + \boldsymbol{F}(\dot{\boldsymbol{\theta}}) + \boldsymbol{G}(\boldsymbol{\theta}) = \boldsymbol{u} + \boldsymbol{\tau}_h$$

$$\mathbf{M}_d\ddot{\mathbf{x}} + \mathbf{B}_d\dot{\mathbf{x}} + \mathbf{K}_d\mathbf{x} = \mathbf{F}_h - \mathbf{F}_e$$

$$F_e = \begin{cases} K_{stiff}\Delta x + B\dot{x} & \text{if } \Delta x > 0 \\ 0 & \text{if } \Delta x \le 0 \end{cases}$$



Leg-Exoskeleton for Rehabilitation Video



Robot for Construction Video

Inverted Pendulums

Moving-Cart Inverted Pendulum Video

Rotary Inverted Pendulum Video

Flywheel based Inverted Pendulum Video

X-Y Planar Inverted Pendulum Video

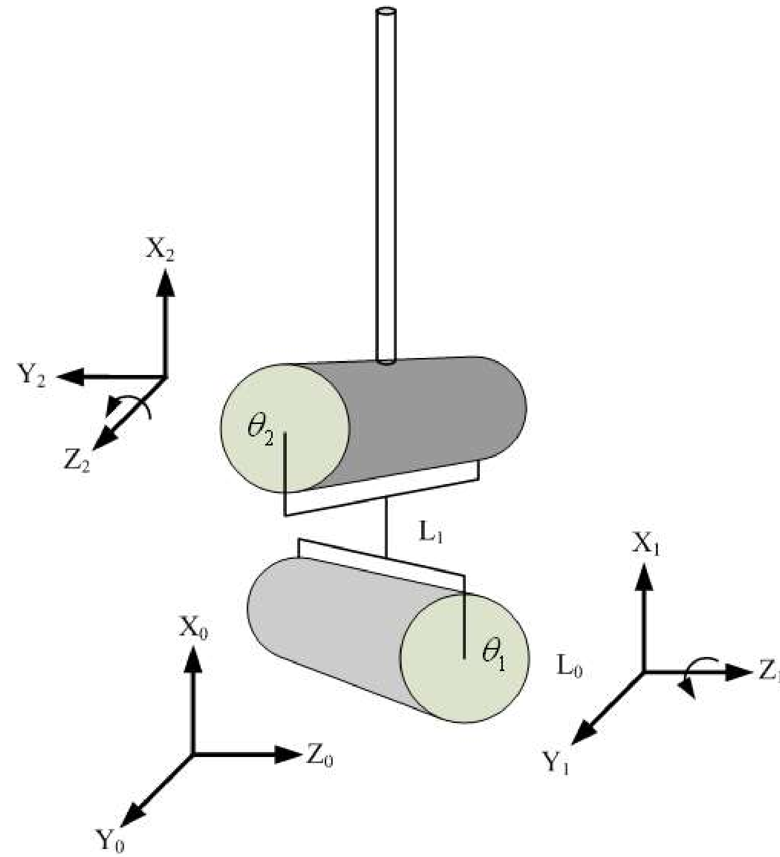
Kinematics Analysis

TABLE I
D-H PARAMETER

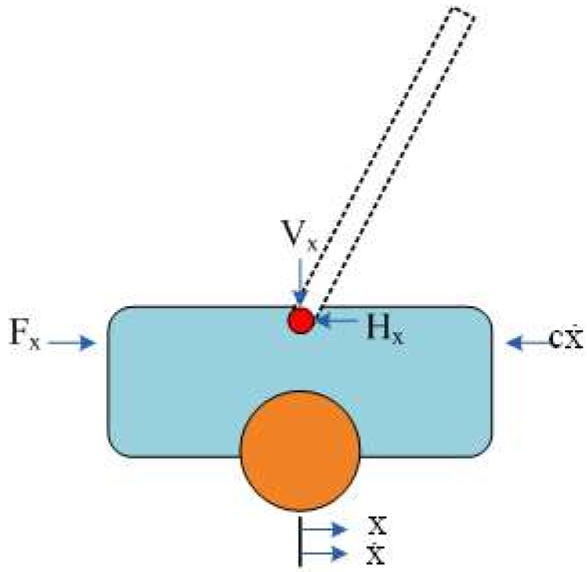
i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	l_0	0	θ_1
2	-90	l_1	0	θ_2

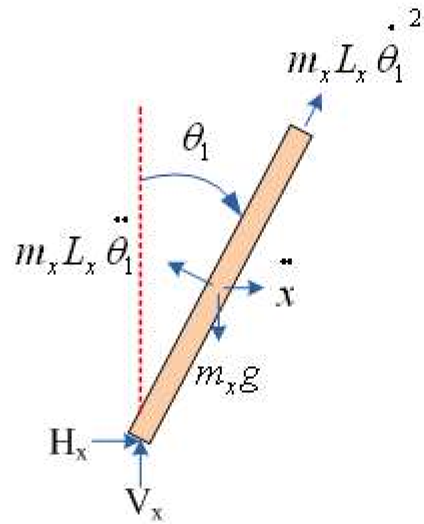
$$T_1^0 = \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & l_0 \\ S\theta_1 & C\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_2^1 = \begin{bmatrix} C\theta_2 & -S\theta_2 & 0 & l_1 \\ 0 & 0 & 0 & 0 \\ -S\theta_2 & -C\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

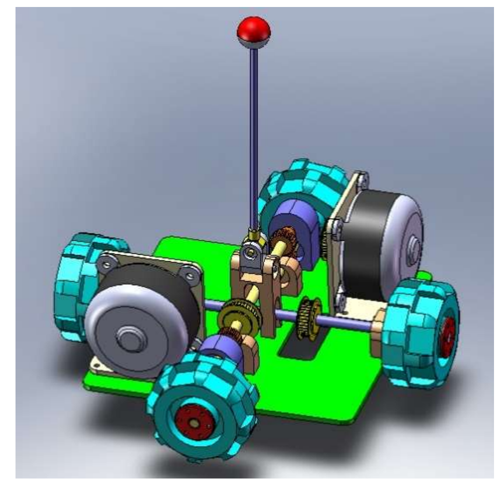
$$T_2^0 = \begin{bmatrix} C\theta_1 C\theta_2 & -C\theta_1 S\theta_2 & -S\theta_1 & l_1 C\theta_1 + l_0 \\ S\theta_1 C\theta_2 & -S\theta_1 S\theta_2 & C\theta_1 & l_1 S\theta_1 \\ S\theta_2 & -C\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Kinetics Analysis







$$\ddot{x} = \frac{-m_X{}^2 l_X{}^2 g\theta_1 + m_X l_X b_X \dot{\theta}_{1L} - J_X c\dot{x} + J_X F_X}{J_X M_X - m_X{}^2 l_X{}^2}$$

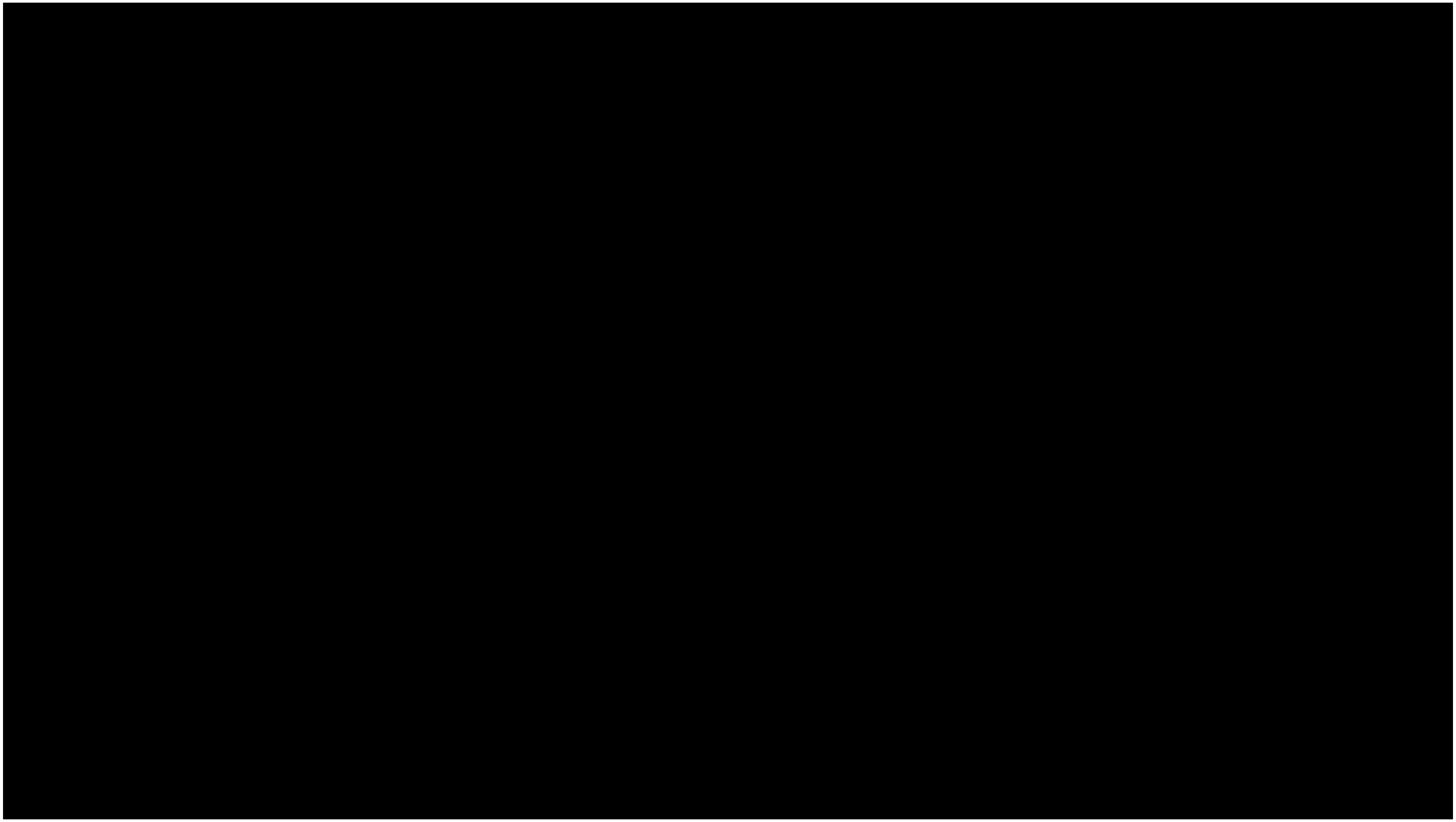
$$\ddot{\theta}_1 = \frac{m_X l_X M g\theta_1 - b_X M_X \dot{\theta}_1 + m_X l_X c\dot{x} - m_X l_X F_X}{J_X M_X - m_X{}^2 l_X{}^2}$$

$$\ddot{y} = \frac{-m_Y{}^2 l_Y{}^2 g\theta_2 + m_Y l_Y b_Y \dot{\theta}_2 - J_Y c\dot{y} + J_Y F_Y}{J_Y M_Y - m_Y{}^2 l_Y{}^2}$$

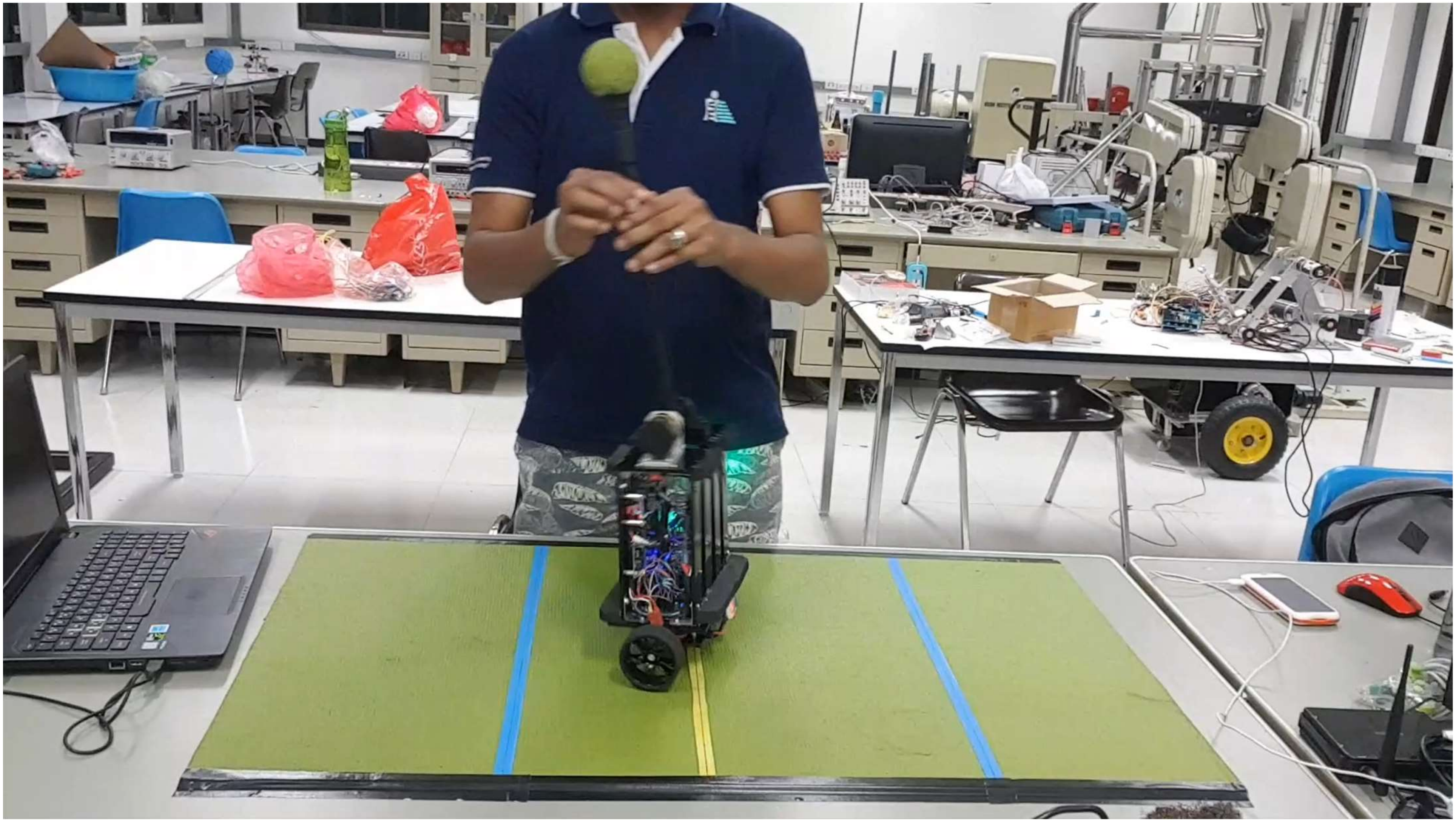
$$\ddot{\theta}_2 = \frac{m_Y l_Y M g\theta_2 - b_Y M_Y \dot{\theta}_2 + m_Y l_Y c\dot{y} - m_Y l_Y F_Y}{J_Y M_Y - m_Y{}^2 l_Y{}^2}$$

Ballbot Video

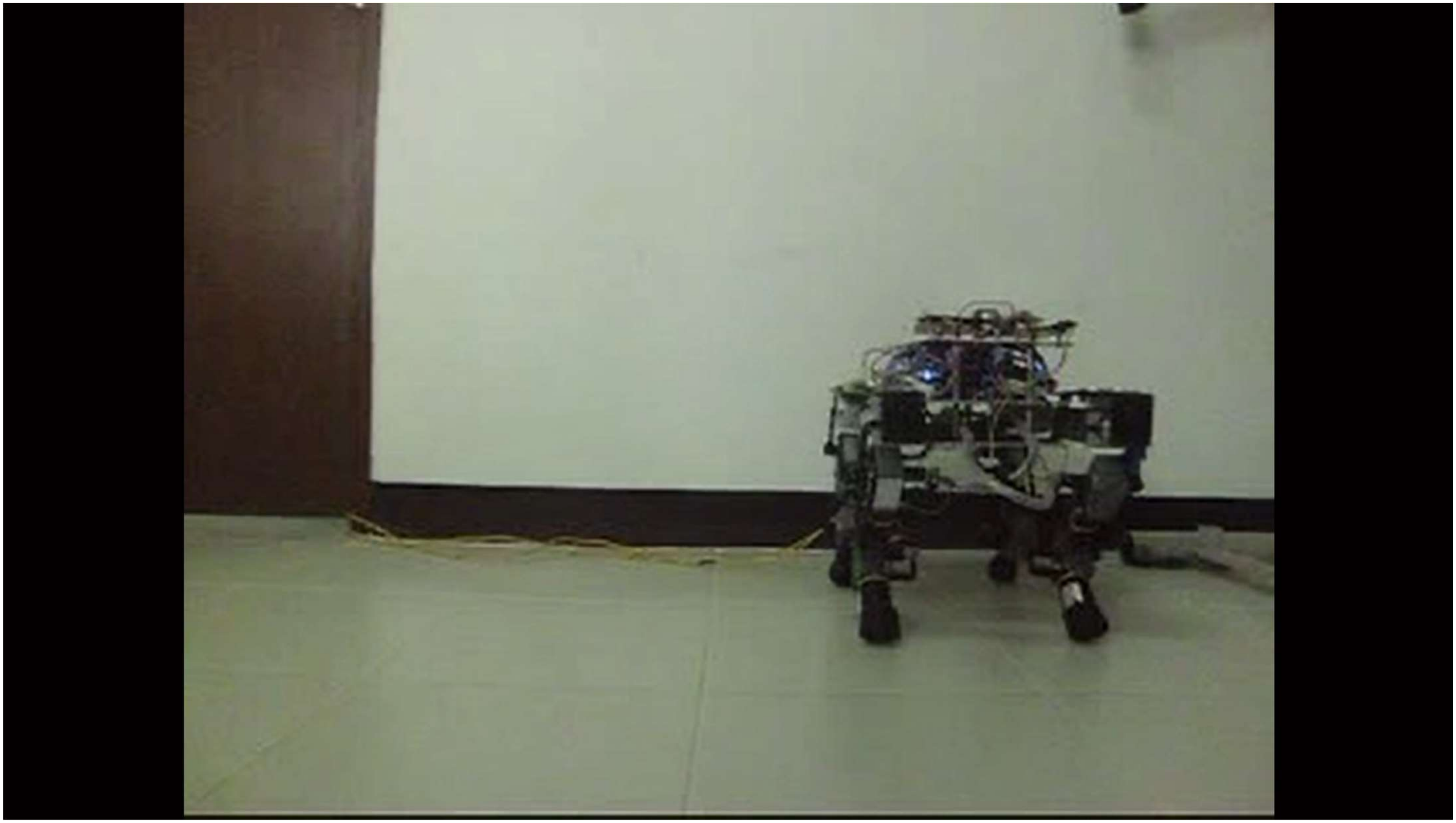
Double-Level Ballbot Video



Inverted Pendulum on Segway Video



Quadruped Robot Video

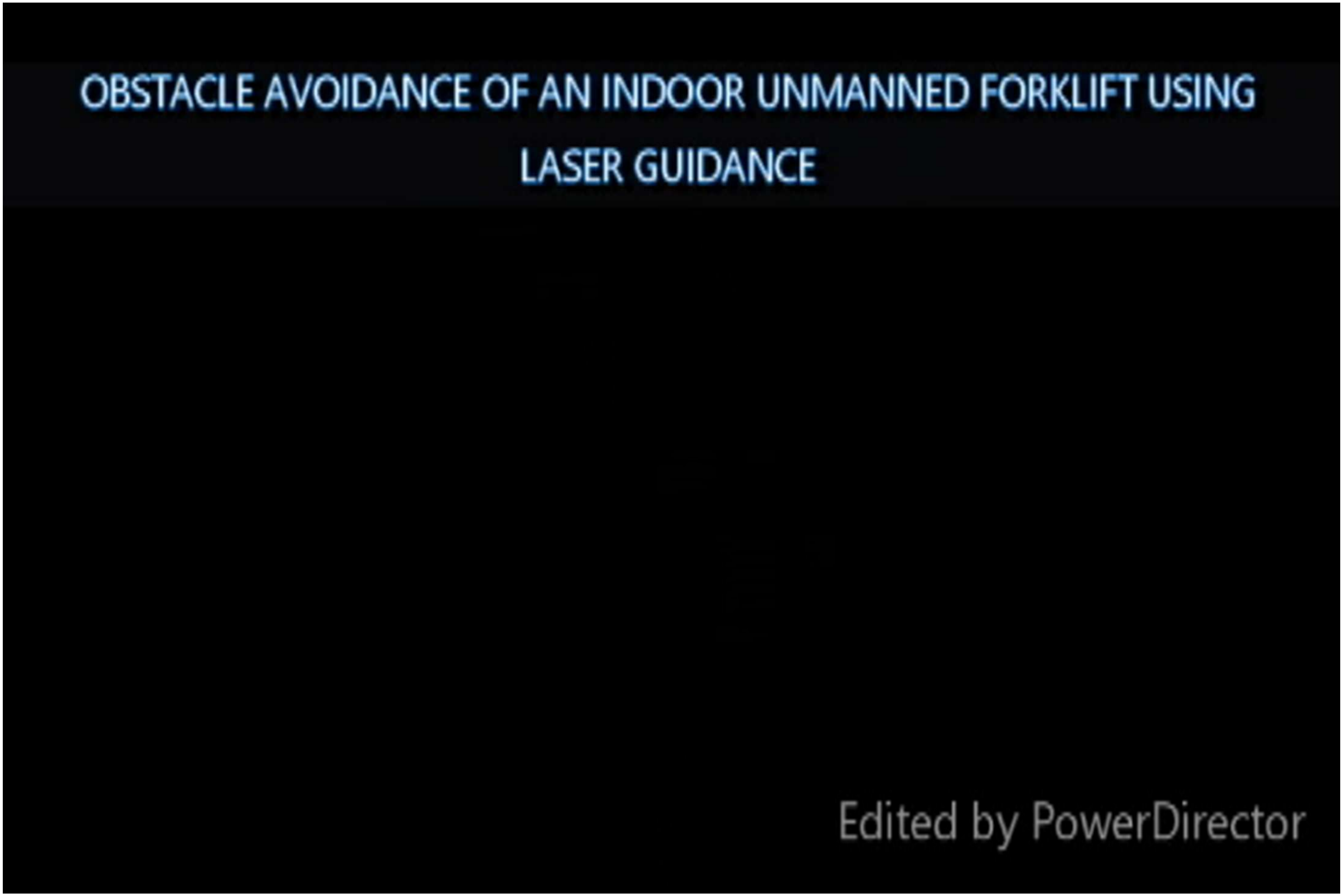


AGV, LGV

Library Robot (Librobo) Video

LGV Forklift Video

LGV Obstacle Avoidance Video



Differential Wheeled Locomotion Mechanism

– Wheel Distance (*WD* (m))

$$WD = \frac{N\pi D}{R}$$

N = Measured Pulse Number
D = Wheel Diameter (m)
R = Encoder Pulse per Revolution

– Robot Distance (*RD* (m))

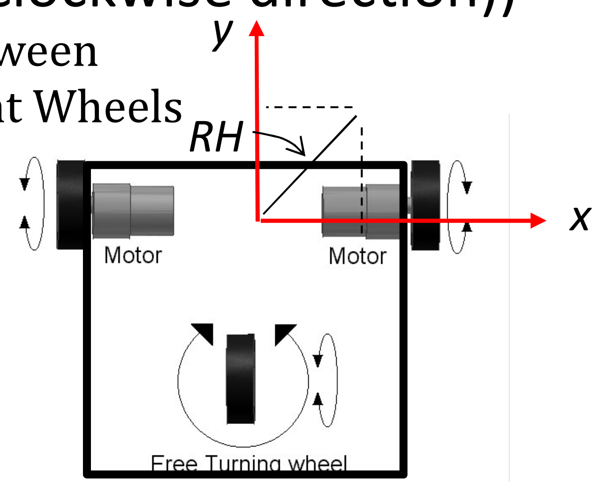
$$RD = \frac{WD_L + WD_R}{2}$$

WD_L = Left Wheel Distance
WD_R = Right Wheel Distance

– Robot Heading (*RH* (degree) positive in clockwise direction))

$$RH = \frac{180(WD_L - WD_R)}{\pi L}$$

L = Distance between Left and Right Wheels



– Robot Coordinate (*x* (m), *y* (m))

$x = \sum(RD \times \sin(\sum RH))$ $\quad$ $y = \sum(RD \times \cos(\sum RH))$

Omni Wheeled Locomotion Mechanism

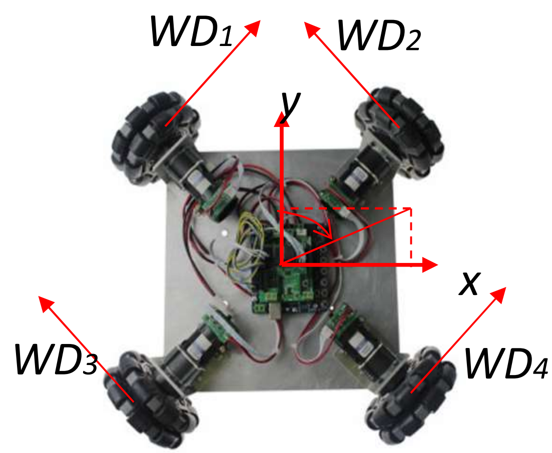
– Wheel Distance (*WD* (m))

$$WD = \frac{N\pi D}{R}$$

N = Measured Pulse Number
D = Wheel Diameter (m)
R = Encoder Pulse per Revolution

– Wheel Coordinate (x_i (m), y_i (m))

$$x_i = \frac{WD_i}{\sqrt{2}} \qquad y_i = \frac{WD_i}{\sqrt{2}}$$



– Robot Coordinate (x (m), y (m))

$$x = \frac{x_1 - x_2 - x_3 + x_4}{4} \qquad y = \frac{y_1 + y_2 + y_3 + y_4}{4}$$

– Robot Heading (*RH* (degree) positive in clockwise direction))

$$RH = \frac{180(WD_1 - WD_2 + WD_3 - WD_4)}{4\pi S}$$

S = Perpendicular Distance between WD vector and Robot Center

Mecanum Wheeled Locomotion Mechanism

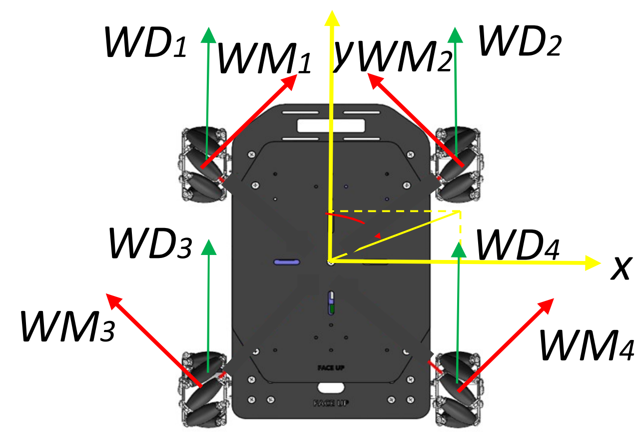
– Wheel Distance (*WD* (m))

$$WD = \frac{N\pi D}{R}$$

N = Measured Pulse Number
D = Wheel Diameter (m)
R = Encoder Pulse per Revolution

– Wheel Real Motion (*WM* (m))

$$WM_i = \frac{WD_i}{\sqrt{2}}$$



– Robot Coordinate (*x* (m), *y* (m))

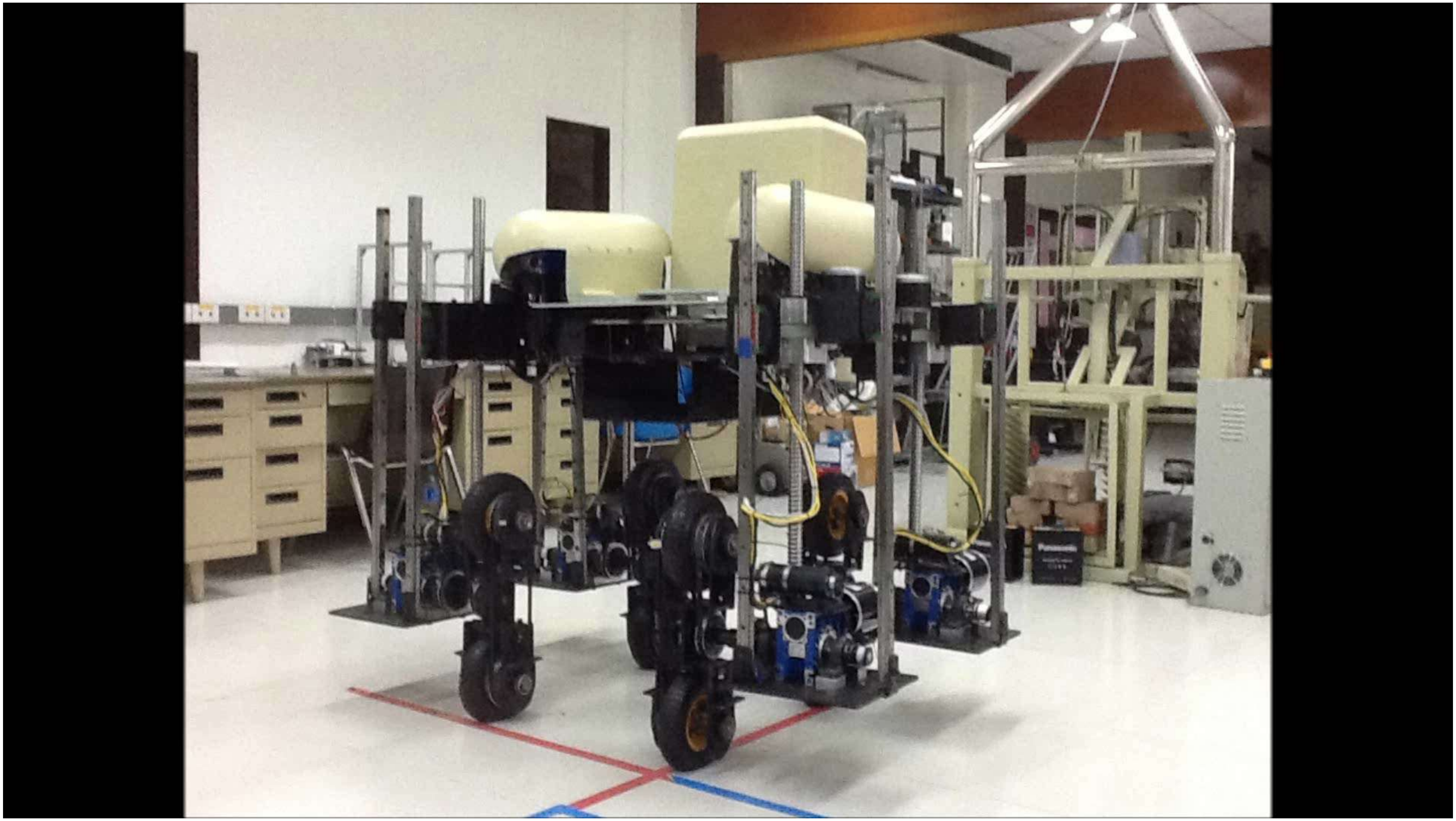
$$x = \frac{WM_1 - WM_2 - WM_3 + WM_4}{4\sqrt{2}} \qquad y = \frac{WM_1 + WM_2 + WM_3 + WM_4}{4\sqrt{2}}$$

– Robot Heading (*RH* (degree) positive in clockwise direction))

$$RH = \frac{180(WM_1 - WM_2 + WM_3 - WM_4)}{4\pi C}$$

C = Perpendicular Distance between WM vector and Robot Center

Stair Climbing Wheelchair Video



Artificial Intelligence

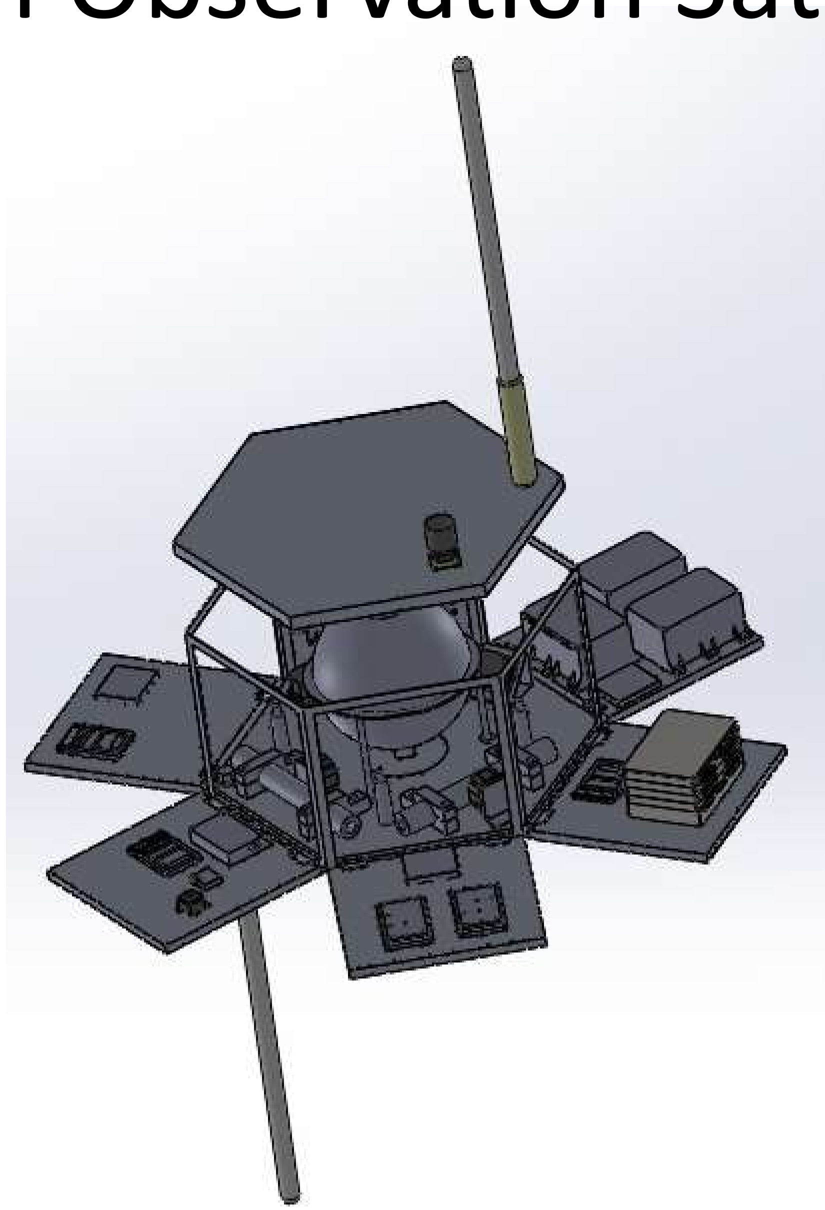
Rubik Solving Video

Robo-Animals

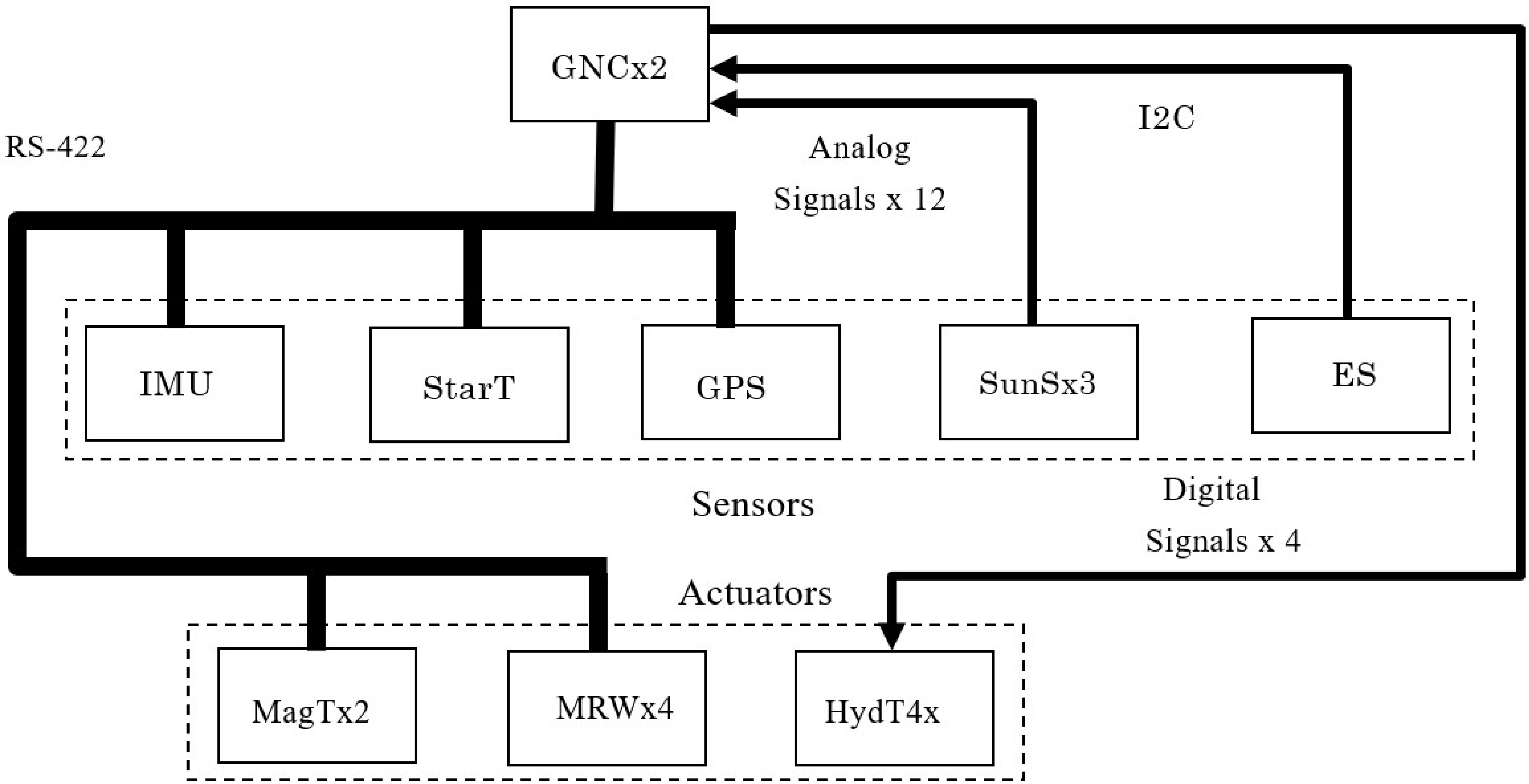
Brain Stimulation Roborat Video

Earth-Observation Sun-Synchronous Satellite

Earth Observation Satellite



GNC Architecture



Scholarships and Fellowships for M.Eng in Mechatronics at AIT

- King's Scholarship (deadline 31 March)
  - Support: tuition fee (B 768,000), registration (B 80,000), accommodation fee, and bursary
  - CGPA $\geq$ 3.50
- RTG Fellowship
  - 100% Fellowship: CGPA $\geq$ 3.00: Support tuition fee (B 768,000), registration (B 80,000)
  - 75% Fellowship: CGPA $\geq$ 2.75: Support tuition fee (B 576,000), registration (B 60,000)

Scholarships and Fellowships for M.Eng in Mechatronics at AIT

- Other Scholarships
  - www.ait.ac.th/admissions/scholarships
- AIT Fellowship
  - 100% Fellowship
  - 75 % Fellowship
  - 50% Fellowship
  - 25% Fellowship

Q & A