NON-LINEAR CONTROL
&
its APPLICATIONS

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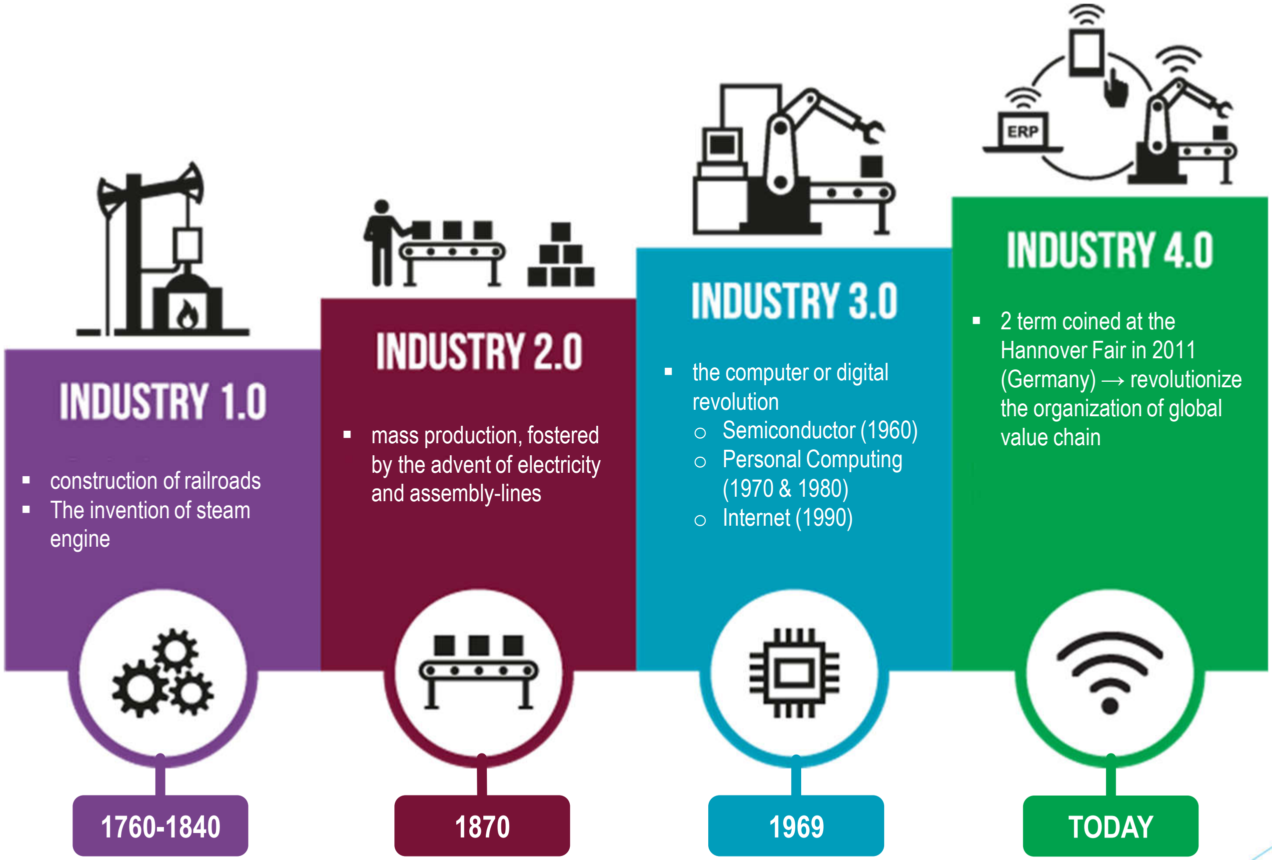
D-105

Industrial Revolution



How old is the control system/ Technology?

Source:Prof Erik Brynjolfsson & Andrew McAfee (MIT)

Why is Non-Linear Control ?

MACHINERY SYSTEM

POWER GENERATION SYSTEM

ROBOTICS SYSTEM

- Mostly, all existing system is non-linear

What is Nonlinear System ?

- A system is nonlinear if the principle of **superposition** does not apply

$$F(x_1 + x_2) = F(x_1) + F(x_2) \qquad \textbf{Additivity}$$

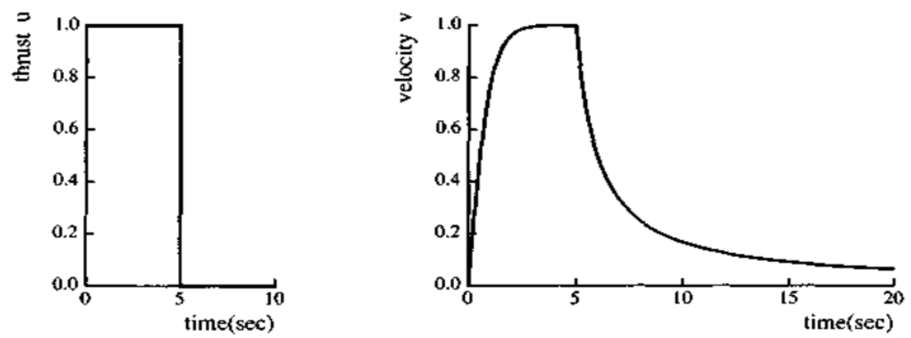
$$F(ax) = aF(x) \qquad \textbf{Homogeneity}$$

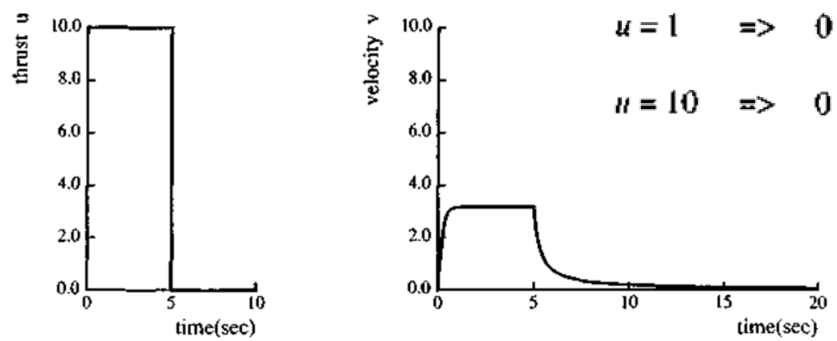
for scalar a.

AN EXAMPLE OF NONLINEAR SYSTEM BEHAVIOR

A simplified model of the motion of an underwater vehicle can be written:

$$\dot{v}_s = -v_s|v_s| + u$$

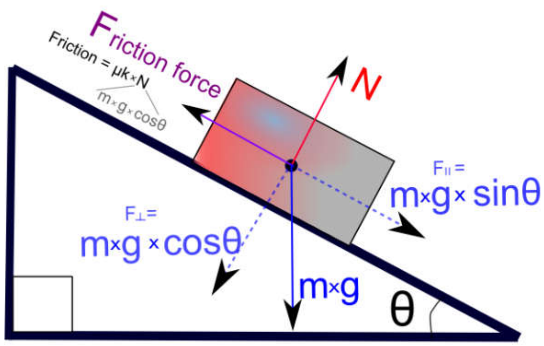




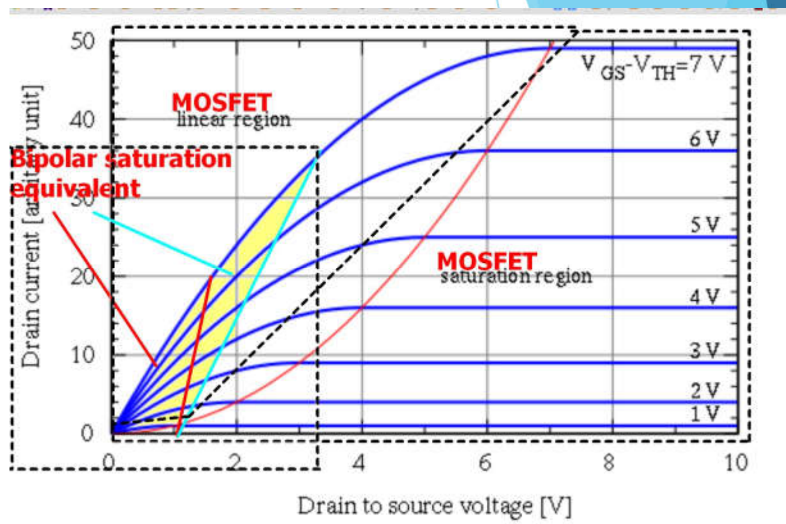
$u = 1 \quad \Rightarrow \quad 0 + |v_s|\, v_s = 1 \quad \Rightarrow \quad v_s = 1$

$u = 10 \quad \Rightarrow \quad 0 + |v_s|\, v_s = 10 \quad \Rightarrow \quad v_s = \sqrt{10} \approx 3.2$

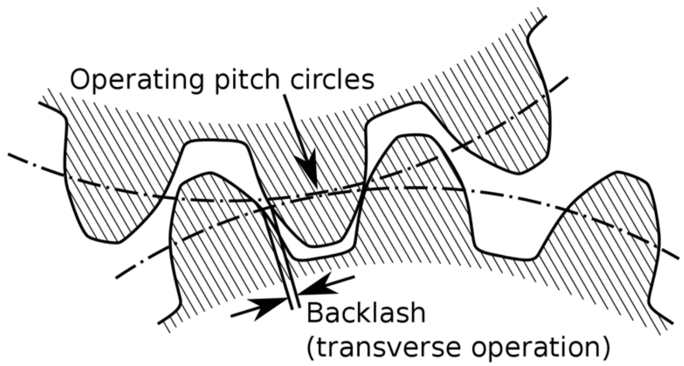
OTHER EXAMPLES OF NON-LINEAR PHENOMENA



FRICTION



SATURATION



BACKLASH

LINEAR vs NON-LINEAR CONTROL

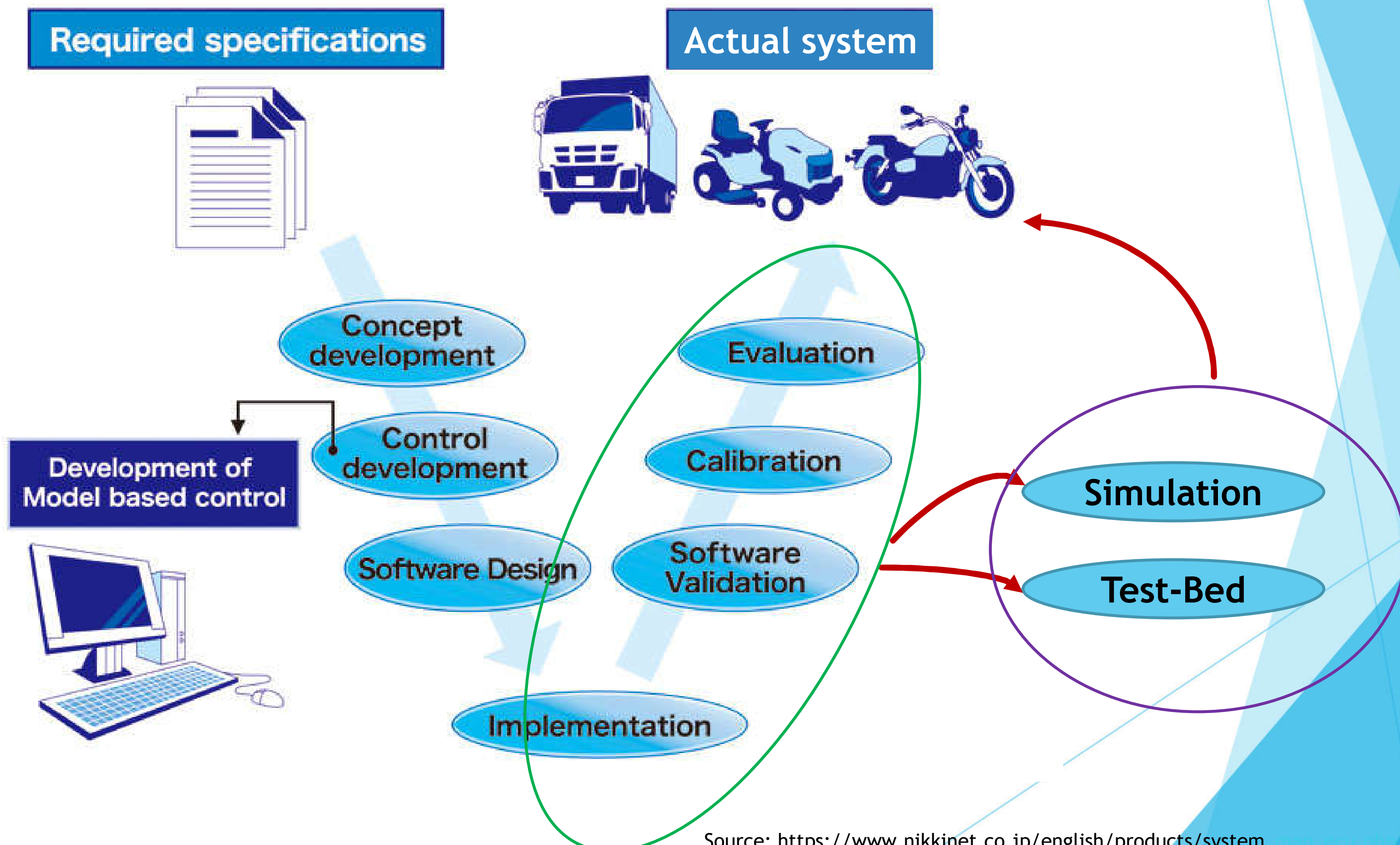
- **LINEAR CONTROL**
  - Only valid for small range operation
  - Cannot handle system with “hard non-linearity”
  - Cannot deal with uncertainties, *e.g.*, parameter changing due to ambient temperature, pressure, etc..

- **NON-LINEAR CONTROL**
  - Valid for wide range operation
  - Can handle system with “hard non-linearity”
  - Can deal with uncertainties, *e.g.*, ambient temperature, pressure, etc..

Type of Control System

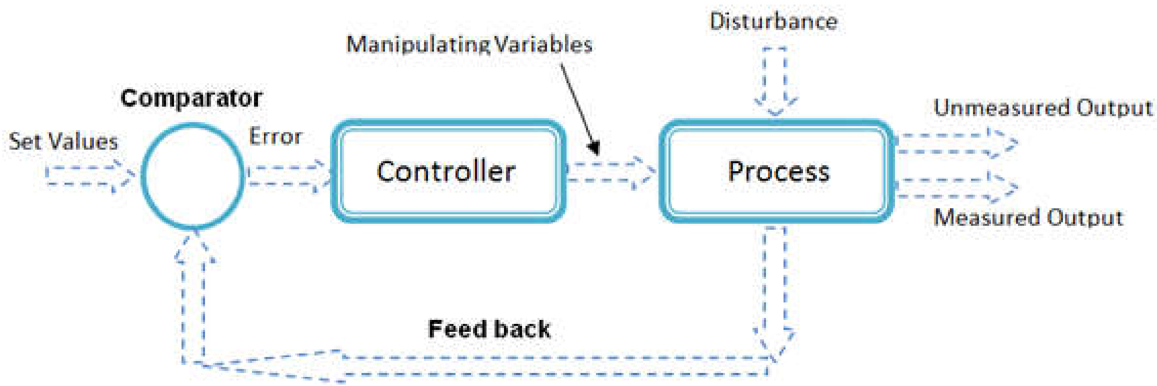
- Based on Systems Type:
  - **Linear Controller (PID, LQR, etc.)**
  - **Non-Linear Controller (SMC, Feedback Linearization, etc.)**
- Based on Design Process:
  - Model based Controller
    - **Need essential information/parameter of the controlled system**
    - **Simple in realization/computation**
    - **Ex: SMC, Backstepping, etc**
  - Non-model Based Controller
    - **No essential information/parameter of the controlled system are needed**
    - **Complex computation**
    - **Ex: Fuzzy, NN, etc.**

CONTROL SYSTEM DESIGN STEPS



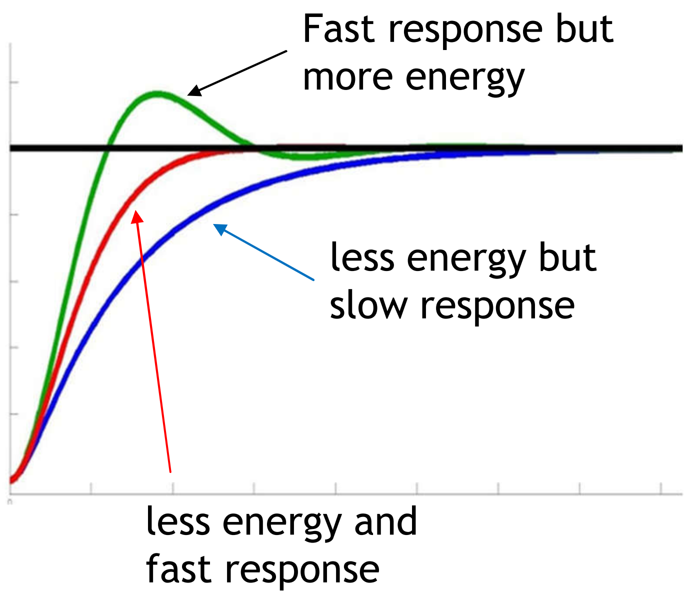
Source: https://www.nikkinet.co.jp/english/products/system

Objective of Control Design



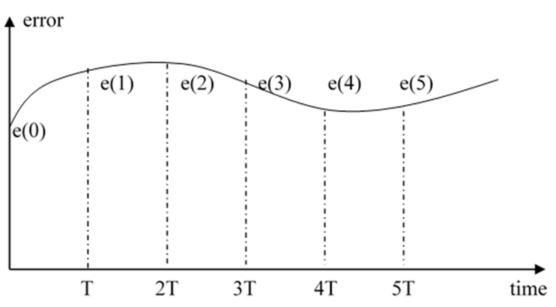
- Main Objective in Control System Design:
  - Stability
  - Performance:
    - Steady State error
    - Transient response (% Overshoot, speed response)
    - Minimize energy consumption
    - comfortability

DESIRED PERFORMANCES OF CONTROL DESIGN

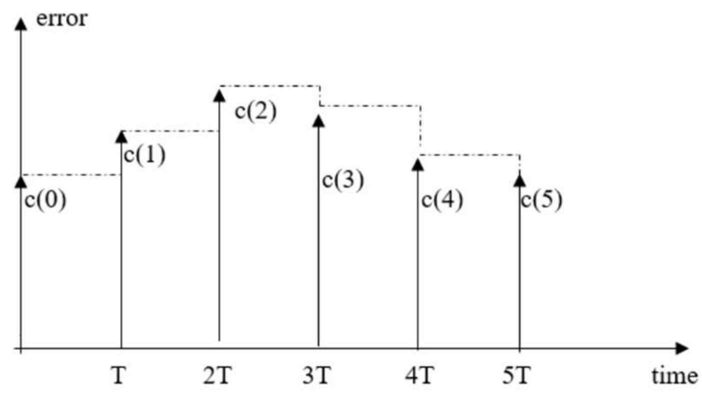


- Robust to disturbance and parameter changing
- Fast response, smooth, and comfort
- Less energy consumption.

OTHER ISSUE IN CONTROL SYSTEM DESIGN AND IMPLEMENTATION

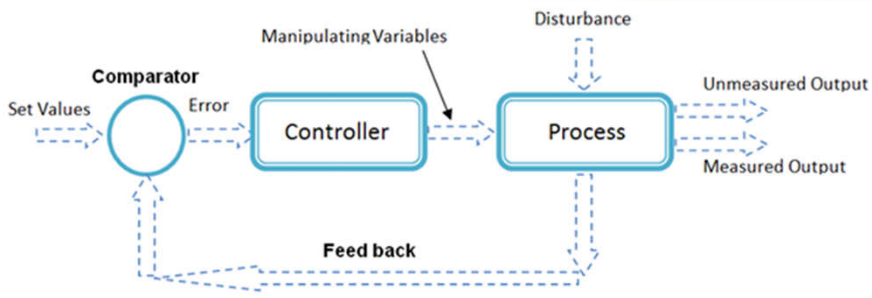


Physical (plant) System



Controller implementation

- ❑ Continuous physical system is controlled in discrete/digitally.
  - ➔ Time sampling becomes critical issue.
  - ➔ The control action lags one step behind.
- ❑ Computation time must be fast enough.
  - ➔ Advance processor/computer
  - ➔ Simple algorithm

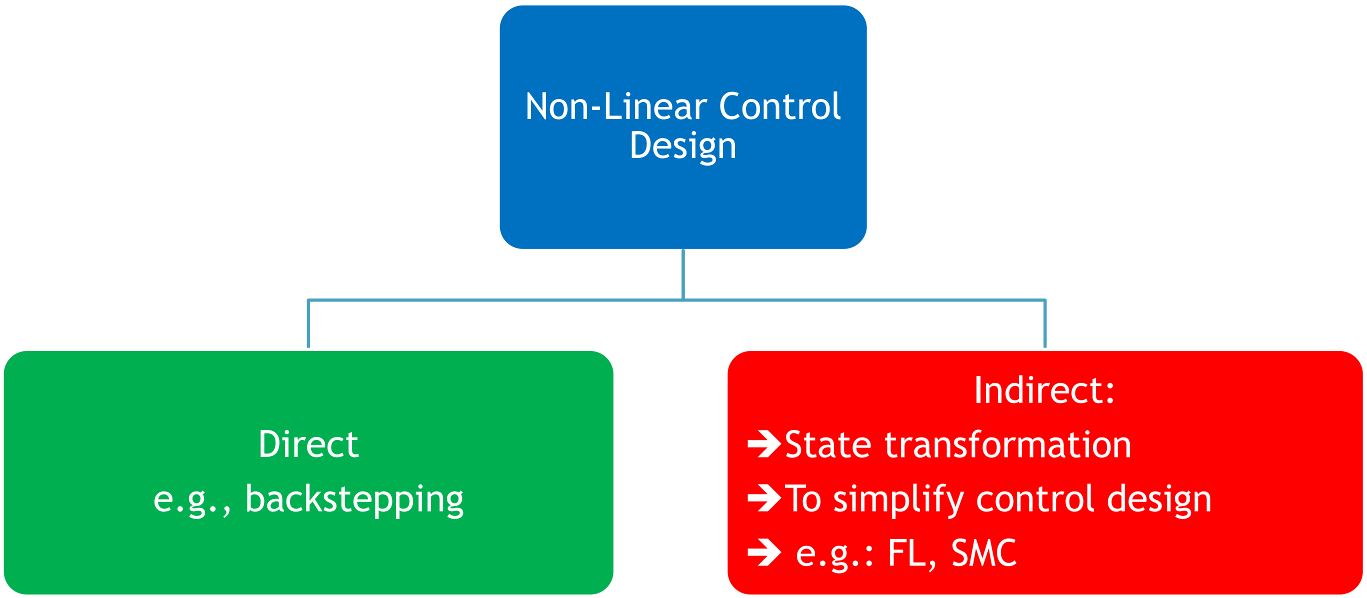


Why is Non-Linear Control ?

- Model based Non-Linear Controller
  - **Simple in realization/computation**
  - **Need essential information/parameter of the controlled system**

➢ Solution for low cost computational resource
➢ Provides robustness

Model Based Non-Linear Control Design

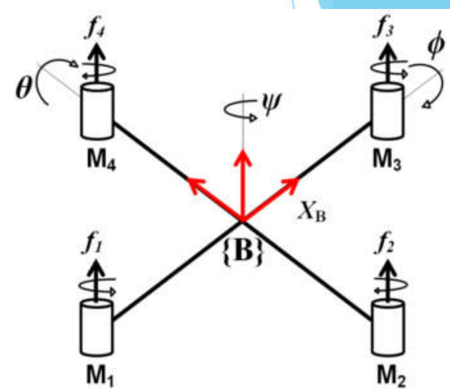


EXAMPLE OF INDIRECT CONTROL DESIGN:

QUADCOPTER DYNAMICS

Translational motion:

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = \begin{bmatrix} (s\phi c\theta s\psi + s\theta c\psi)\frac{u_1}{m} \\ (-s\phi c\theta c\psi + s\theta s\psi)\frac{u_1}{m} \\ c\phi c\theta \frac{u_1}{m} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ -g \end{bmatrix}$$



Rotational motion :

$$\begin{bmatrix} \ddot{\phi} \\ \ddot{\theta} \\ \ddot{\psi} \end{bmatrix} = J^{-1} \begin{bmatrix} K_1(\Theta, \dot{\Theta}) \\ K_2(\Theta, \dot{\Theta}) \\ K_3(\Theta, \dot{\Theta}) \end{bmatrix} + J^{-1} \begin{bmatrix} u_2 \\ u_3 \\ u_4 \end{bmatrix}$$

$u_1 = \sum_{i=1}^{4} f_i$ ⟶ x, y, z motions

$u_2 = L(f_4 - f_2)$ ⟶ ϕ motion

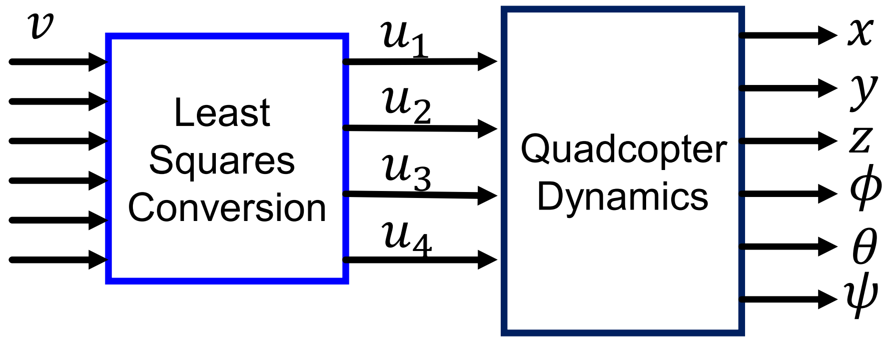
$u_3 = L(f_1 - f_3)$ ⟶ θ motion

$u_4 = d(f_4 + f_2 - f_1 - f_3)$ ⟶ ψ motion

$$\ddot{\xi} = f_1(\Theta, \dot{\Theta}) + f_2(\Theta, u)$$

⟶ **Underactuated system**

CONTROL STRUCTURE



$$\ddot{\xi} = f_1(\Theta, \dot{\Theta}) + f_2(\Theta, u)$$

State transformation

$$v = [v_x, v_y, v_z, v_\phi, v_\theta, v_\psi]^T$$

$$\eta_1 = \xi = [x, y, z, \phi, \theta, \psi]^T \quad \eta_2 = \dot{\xi}$$

$$\dot{\eta}_1 = \eta_2$$

$$\dot{\eta}_2 = v + \gamma_d$$

Complete linearization and decoupling → Any control strategy can be applied.

Controller Design: SMC

➔ To guarantee existence of Sliding Mode

$$s = \dot{s} = 0$$

$$\dot{\eta}_1 = \eta_2$$

$$\dot{\eta}_2 = v + \gamma_d$$

$$s = (F + \Psi)e + \dot{e}$$

$$e = \eta_1 - \eta_{1d}$$

$$\dot{s} = (F + \Psi)\dot{e} + \dot{\Psi}e + v + \gamma_d - \dot{\eta}_{2d}$$

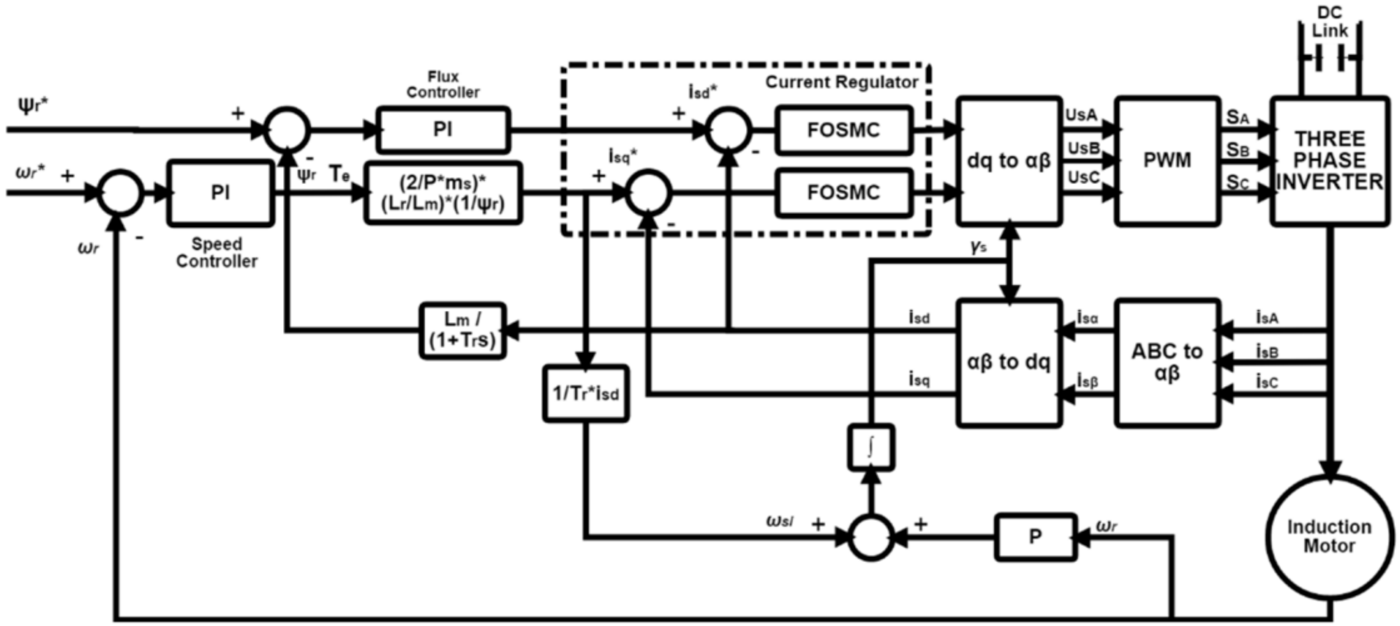
$$v = v_{eq} - C_a\left(|s|^{\frac{1}{2}}\operatorname{sign}(s) + Gs\right) - \int_0^t C_b\left(\frac{1}{2}\operatorname{sign}(s) + \frac{3G}{2}|s|^{\frac{1}{2}}\operatorname{sign}(s) + G^2 s\right)dt,$$

$$v_{eq} = -(F + \Psi)\dot{e} - \dot{\Psi}e + \dot{\eta}_{2d},$$

↳ Simple for implementation

EXAMPLE OF INDIRECT CONTROL DESIGN:

INDUCTION MOTOR



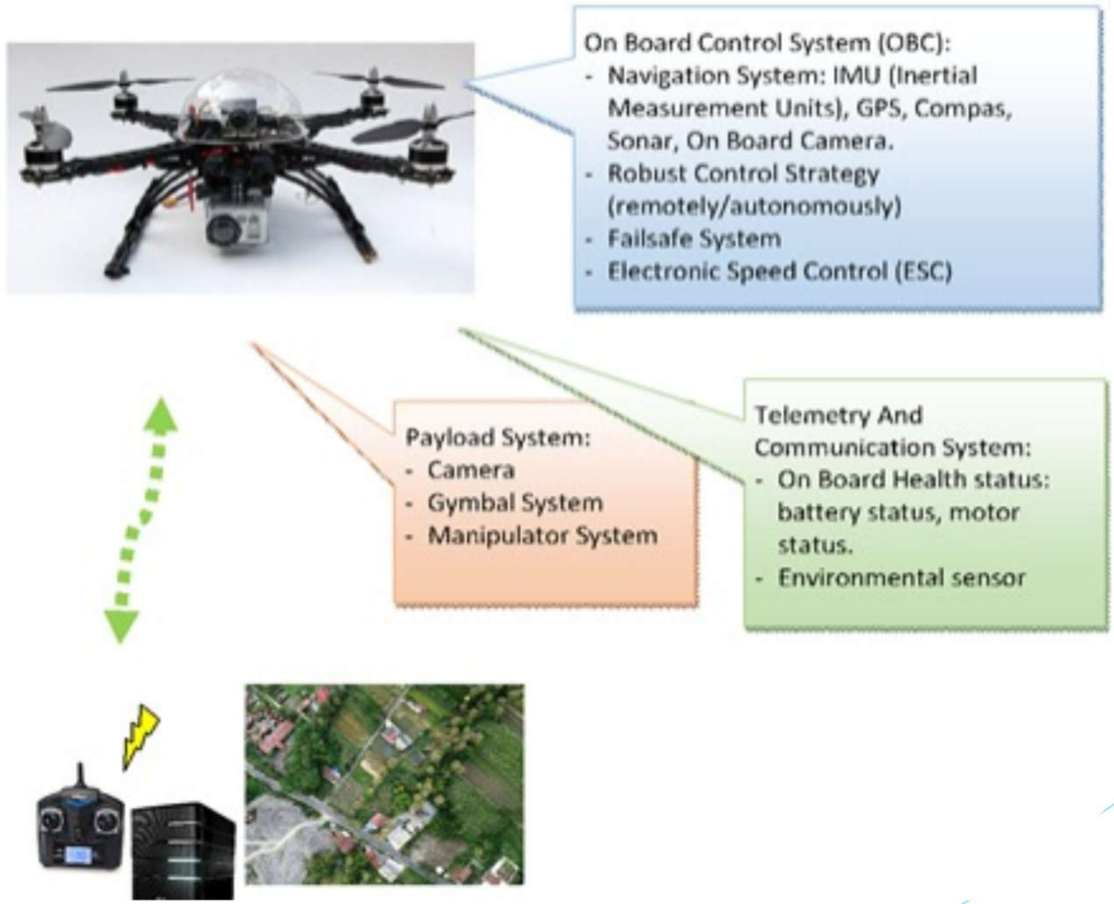
$$U_{FOSMC}\,(U_{sd}) = \sigma L_s \left(\dot{i}_{sd_{desire}} + \frac{R_{sm}}{\sigma L_s} i_{sd} - \omega_s i_{sq} - \frac{L_m}{L_r T_r}\,\psi_r\right) + k\,[S] + \beta\, sign\,[S]$$

$$U_{FOSMC}\,(U_{sq}) = \sigma L_s \left(\dot{i}_{sq_{desire}} + \frac{R_{sm}}{\sigma L_s} i_{sq} - \omega_s i_{sd} - \frac{L_m \omega_{sl}}{L_r}\,\psi_r\right) + k\,[S] + \beta\, sign[S]$$

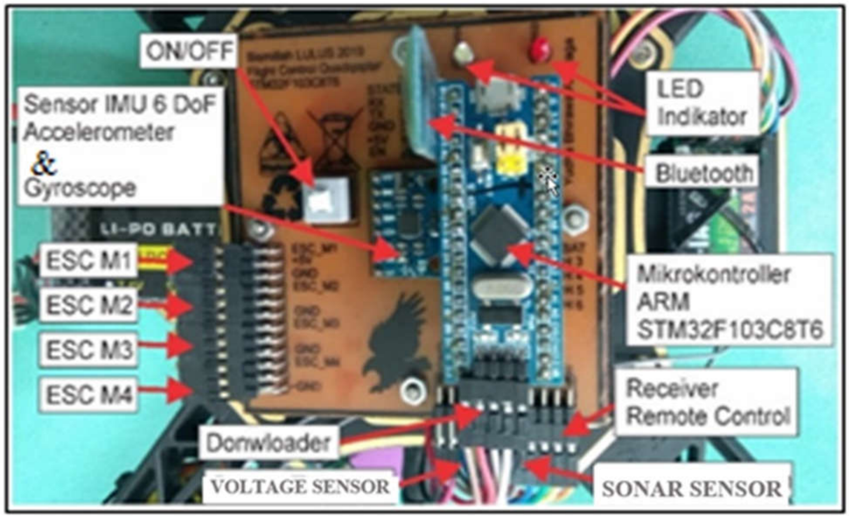
$$S = \left(\frac{d}{dt} + \lambda\right)^{n-1} \mathrm{e}$$

Research Topics

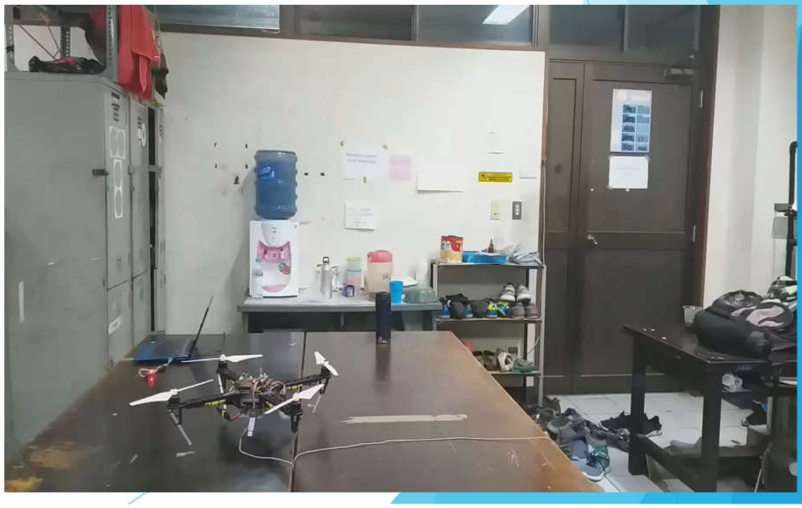
RESEARCH FRAMEWORK ON UNMANNED AERIAL VEHICLE



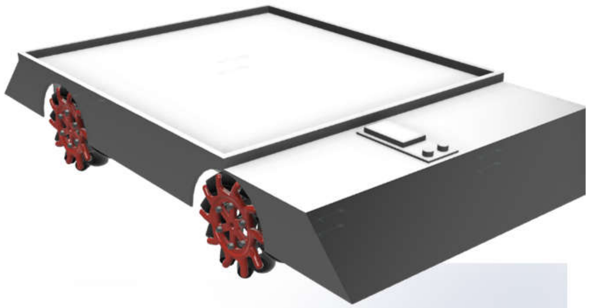
Achievements

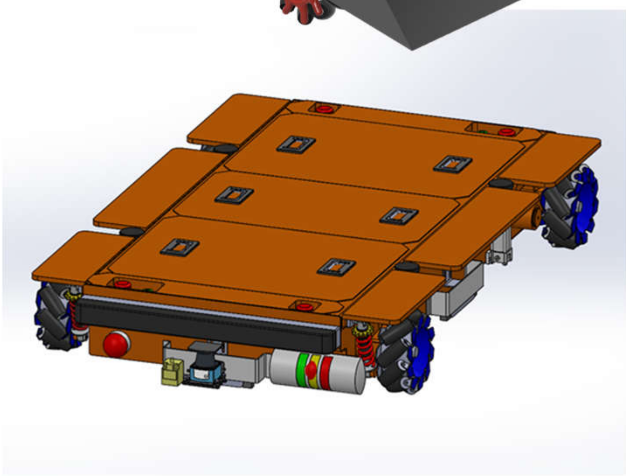


1. Journal paper
2. International conference

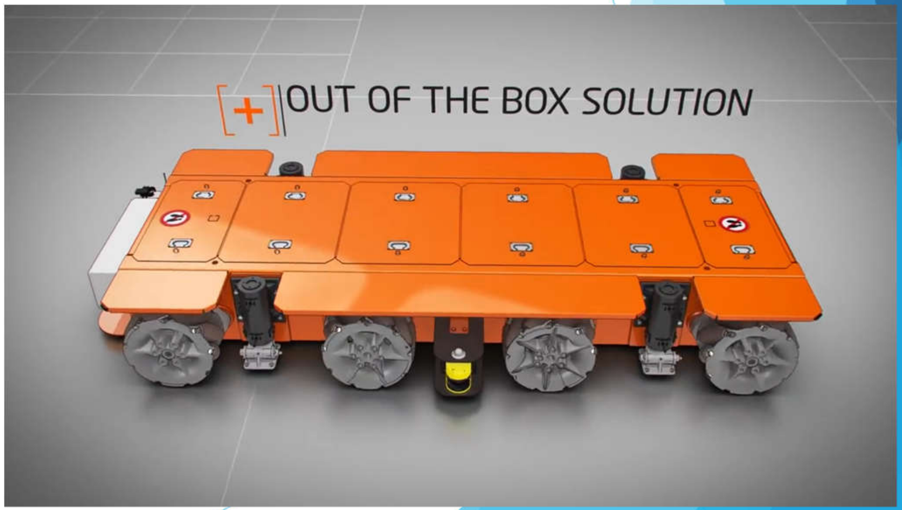


RESEARCH ON AUTOMATIC GUIDED VEHICLE (AGV)



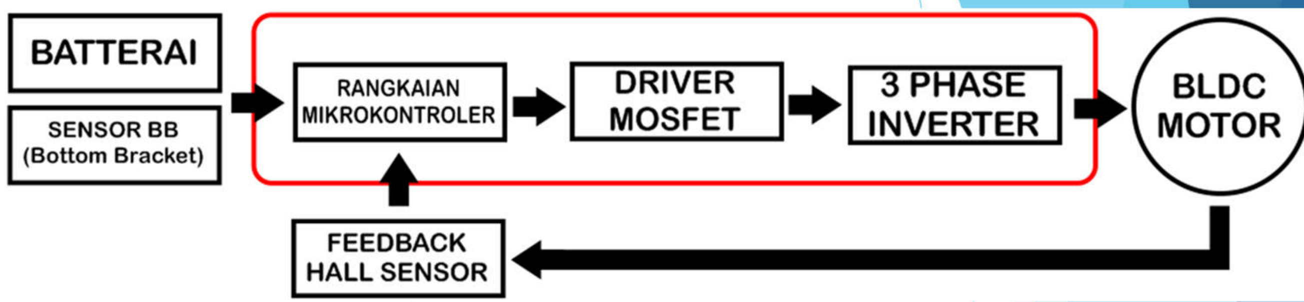


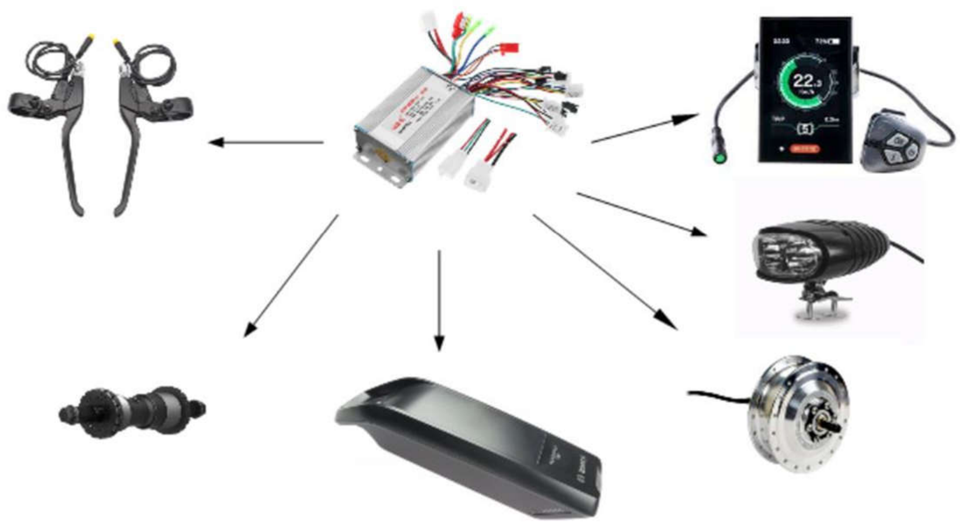
- MOTION CONTROL
- MAPPING AND LOCALIZATION
- AUTOMATIC DOCKING AND CHARGING



https://www.youtube.com/watch?v=kN9a7W_hnSQ

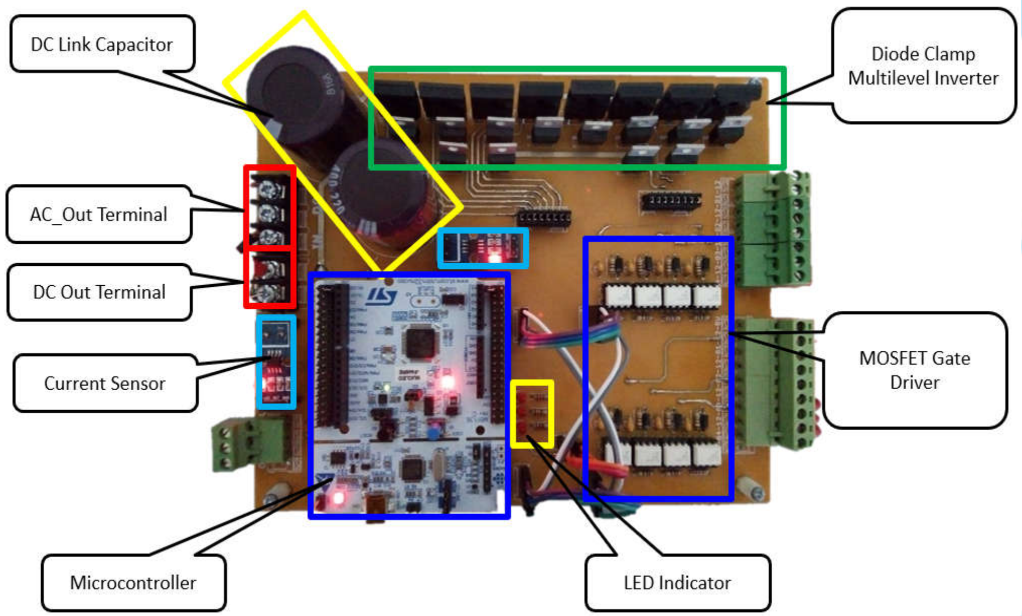
RESEARCH ON POWER ASSISTED e-BICYCLE

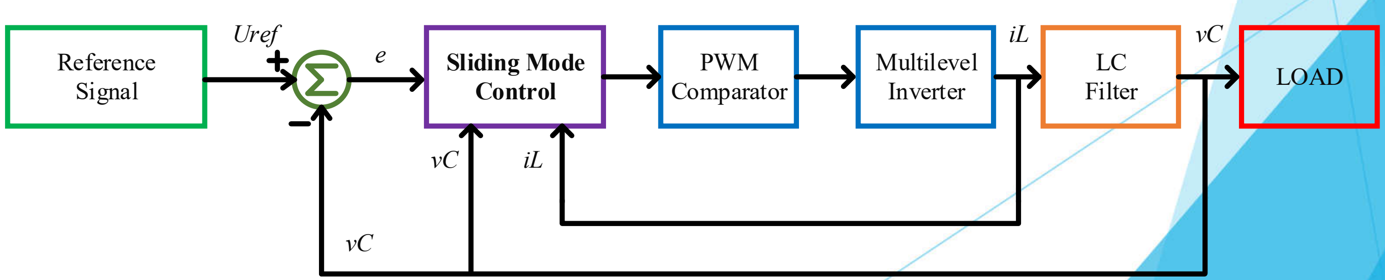




Renewable Energy

Power Inverter





Everything is nothing without POWER, but POWER is nothing without CONTROL.