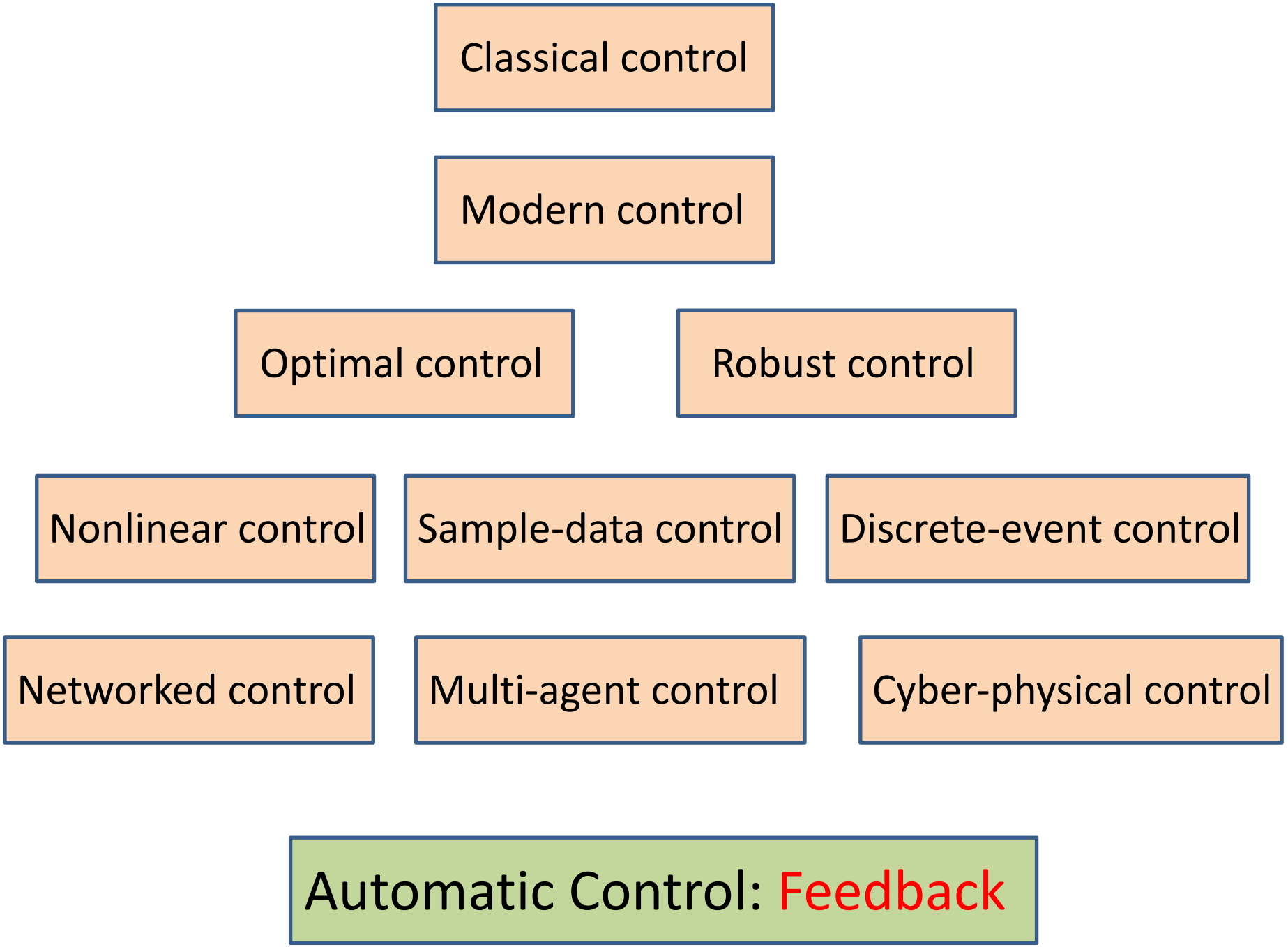
システム制御工学
(Classical Control)

Instructor: Kai Cai

Period: 2022.04-2022.07


Classical control
Modern control
Optimal control
Robust control
Nonlinear control
Sample-data control
Discrete-event control
Networked control
Multi-agent control
Cyber-physical control
Automatic Control: Feedback

What is automatic control?


KHR-3HV
KONDO

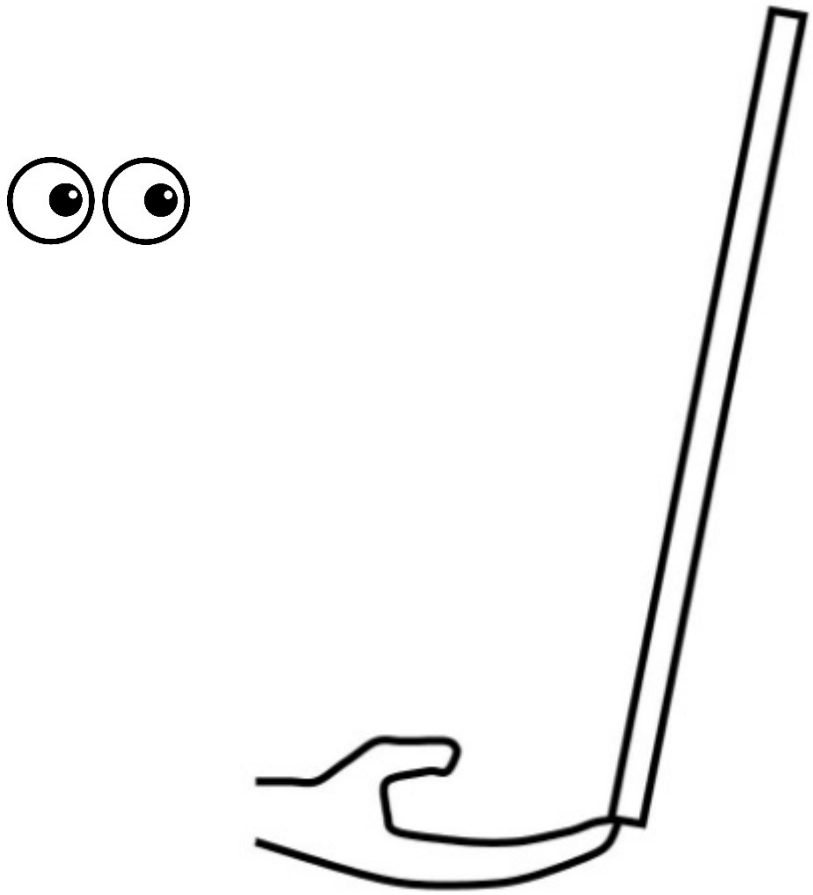

Google
6VVA091

What is automatic control?

- System: some entity that dynamically changes over time

- Control: influence the change in a desired way (by observing the system and making decisions)

Balance a stick



Building blocks

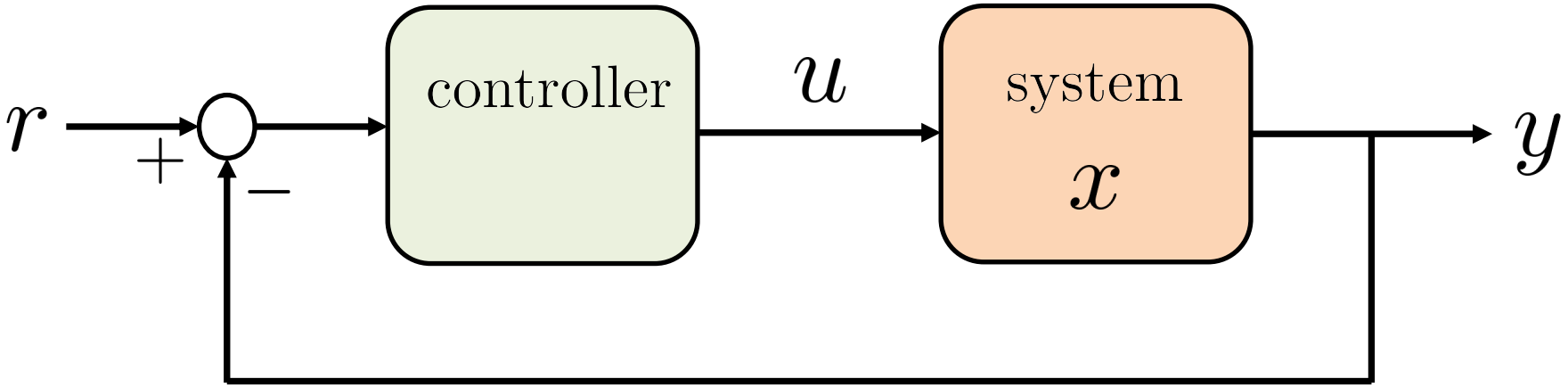
State x : represents what the system is currently doing

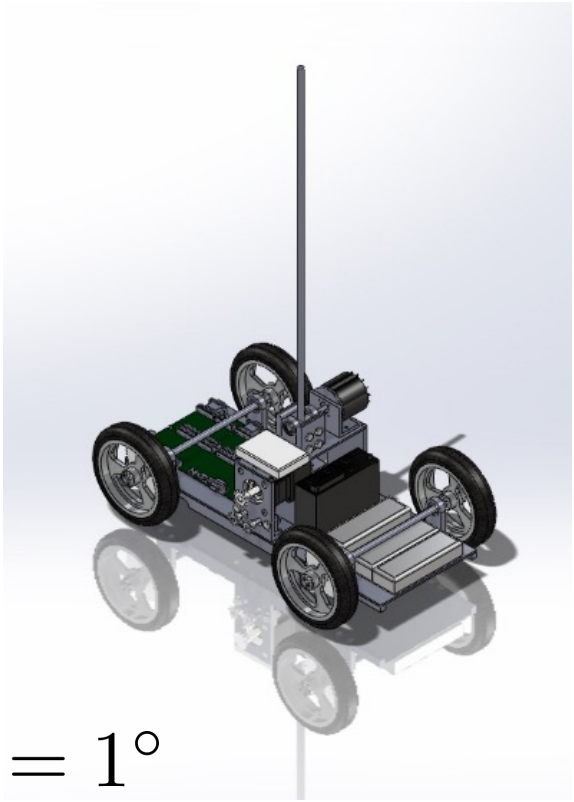
Output y : measurement of some aspects of the system

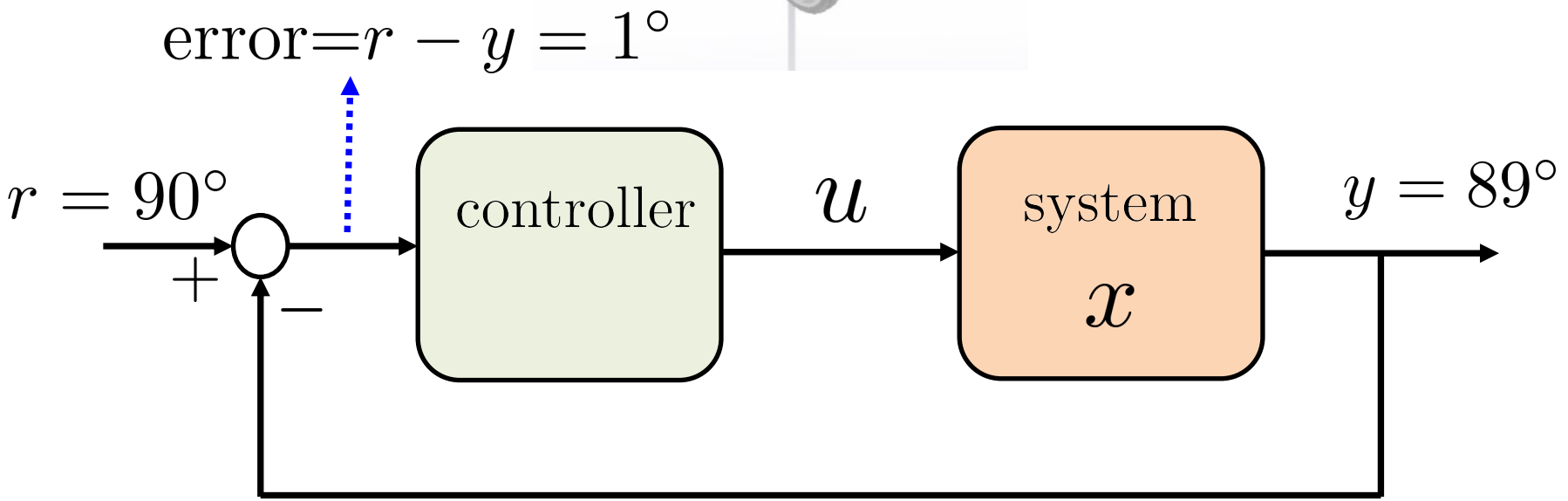
Reference r : what the system is expected to do

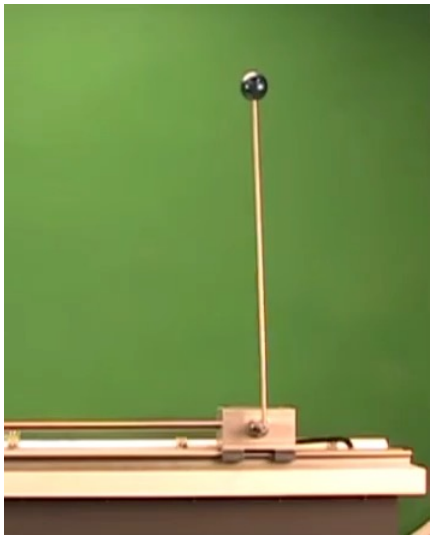
Input u : control decisions/signals

Feedback : mapping from output to input






error=$r - y = 1°$
$r = 90°$
+
−
controller
u
system
x
$y = 89°$



https://www.youtube.com/watch?v=a4c7AwHFkT8

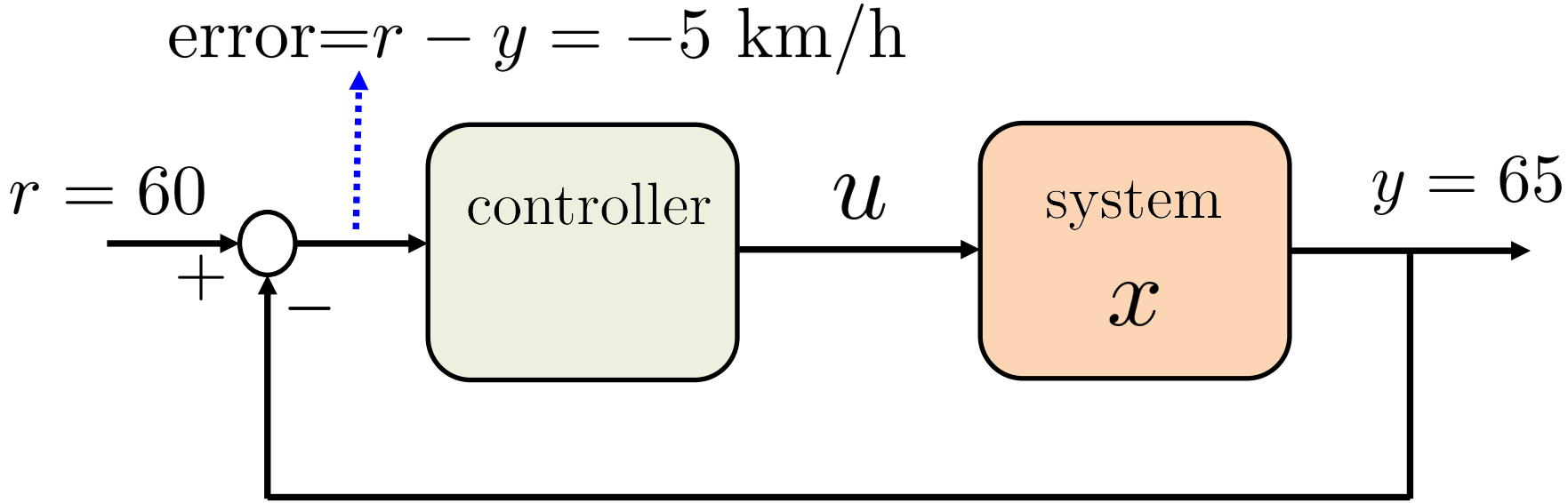
https://www.youtube.com/watch?v=FFW52FuUODQ

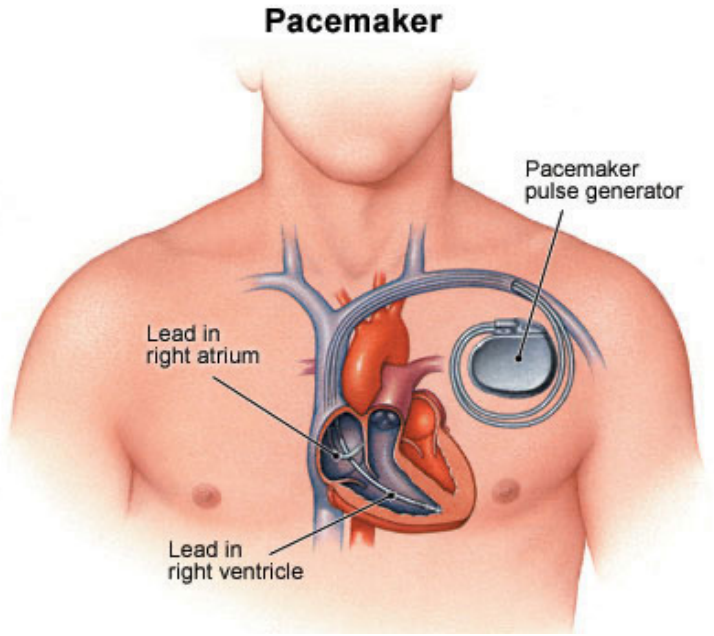
Murata robots

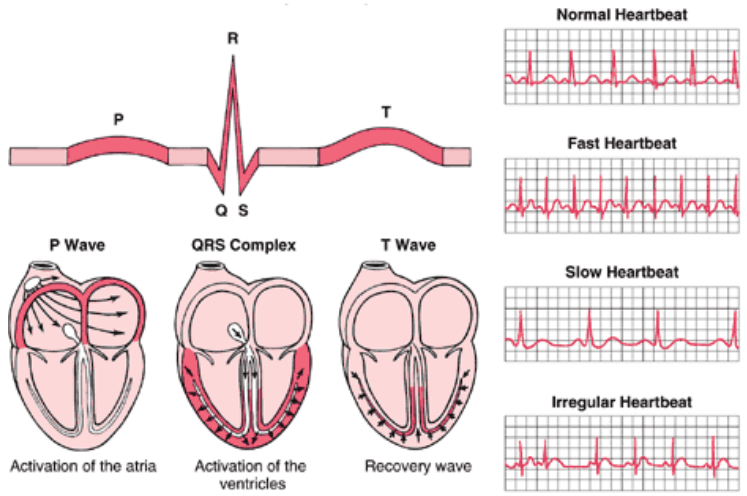
Segways at Chubu International Airport

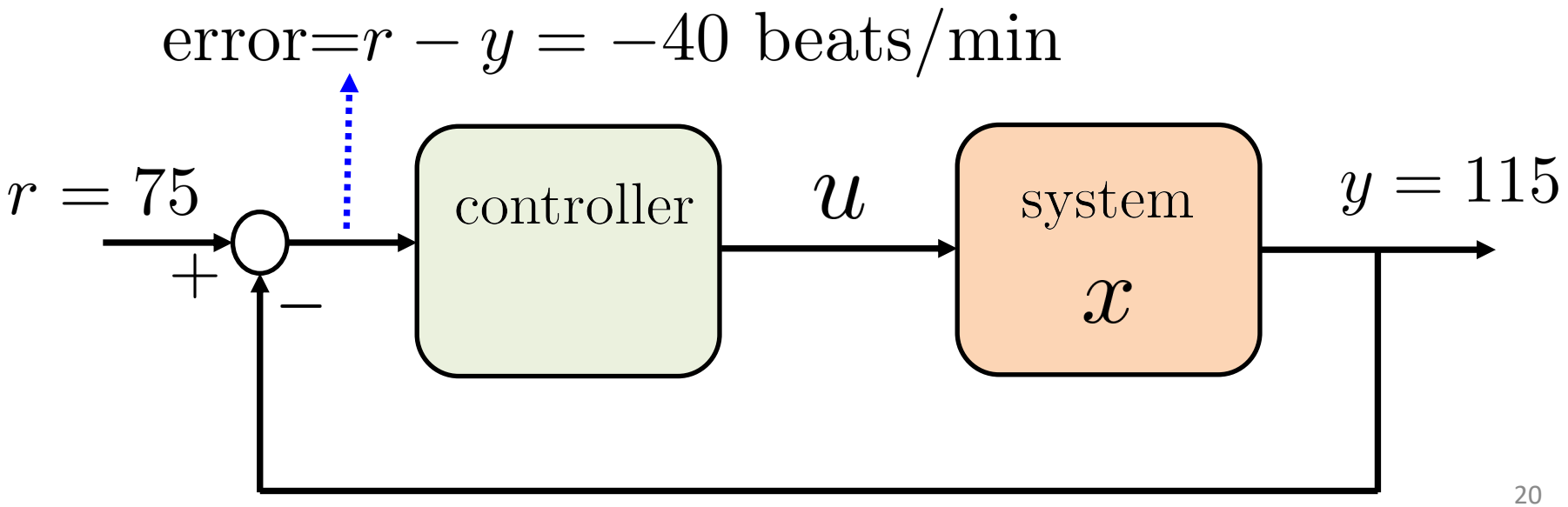
SpaceX rockets

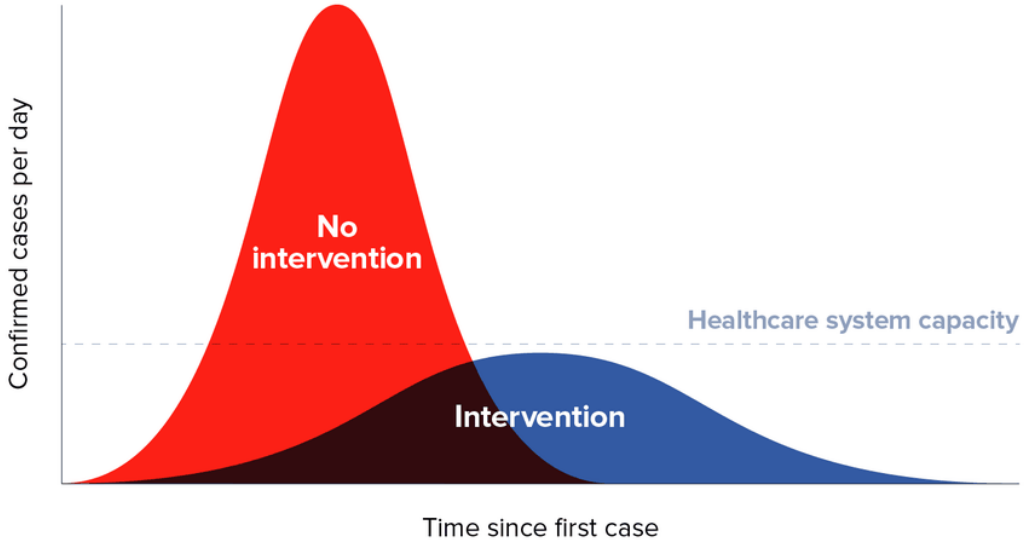

x 1000
KM/H
wikiHow to Use Cruise Control on a C

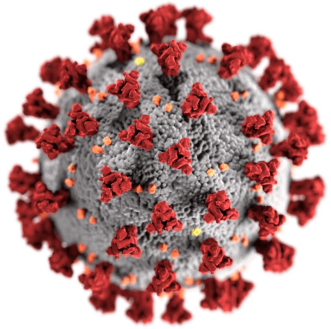

error$=r-y=-5$ km/h
$r=60$
+
−
controller
u
system
x
$y=65$


Pacemaker
Pacemaker pulse generator
Lead in right atrium
Lead in right ventricle

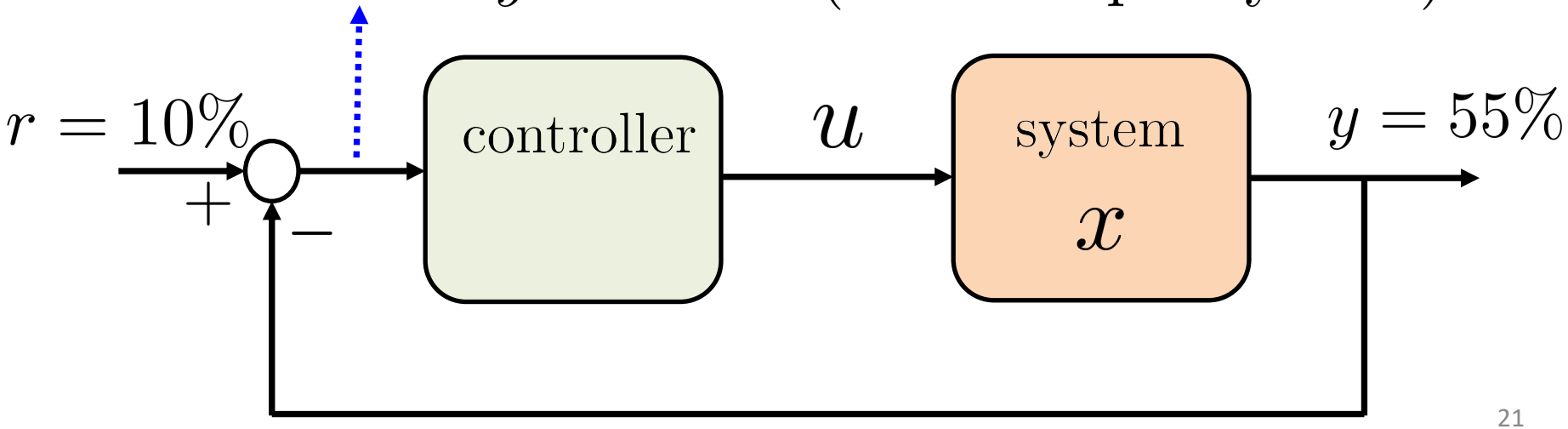

R
P
T
Q S
P Wave
QRS Complex
T Wave
Activation of the atria
Activation of the ventricles
Recovery wave
Normal Heartbeat
Fast Heartbeat
Slow Heartbeat
Irregular Heartbeat


error$=r-y=-40$ beats/min
$r=75$
+
−
controller
u
system
x
$y=115$





$$\text{error} = r - y = -45\% \text{ (bed occupancy rate)}$$

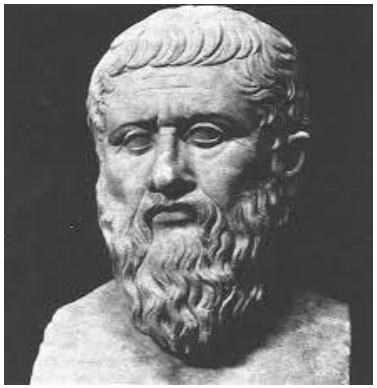


Examples

- Cruise control / lane following
- Air-conditioning / thermostat
- Healthcare
- Epidemics
- Stock market
- Power/energy networks
- Multi-robot formation
- Social opinions

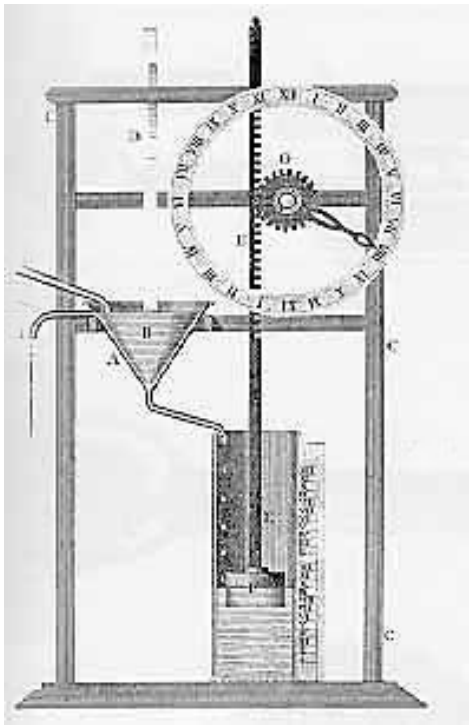
Brief history of feedback in automatic control

Hydraulic feedback mechanism



- Ctesibius (Ktesibios), BCE 3

Alexandria, Ptolemaic Egypt



- Water clock

- Today's flush toilet

Heat feedback mechanism

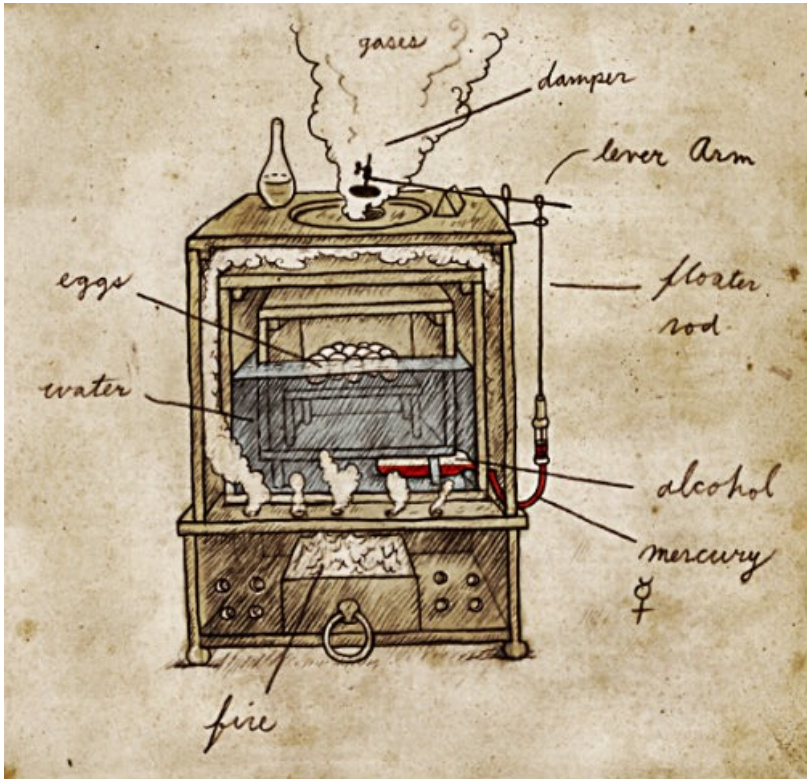
- Cornelis Drebbel, AD 17

Netherlands

- Furnace for

chicken egg incubator

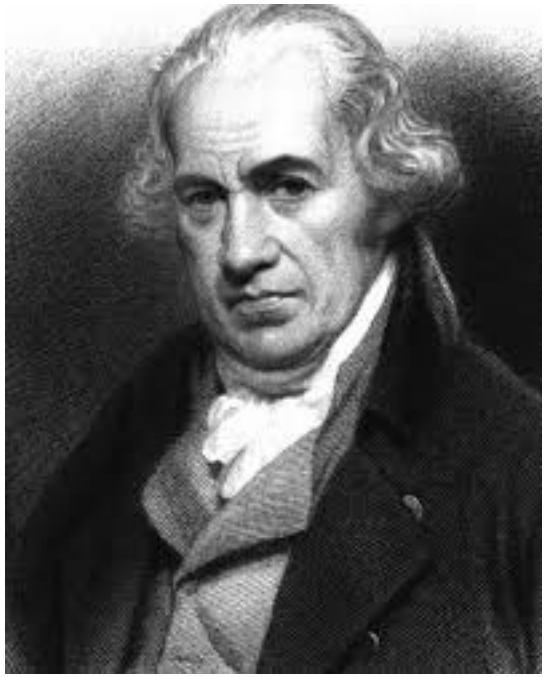
- Today's oven



Mechanical feedback mechanism

- James Watt, AD 18

Scotland, UK

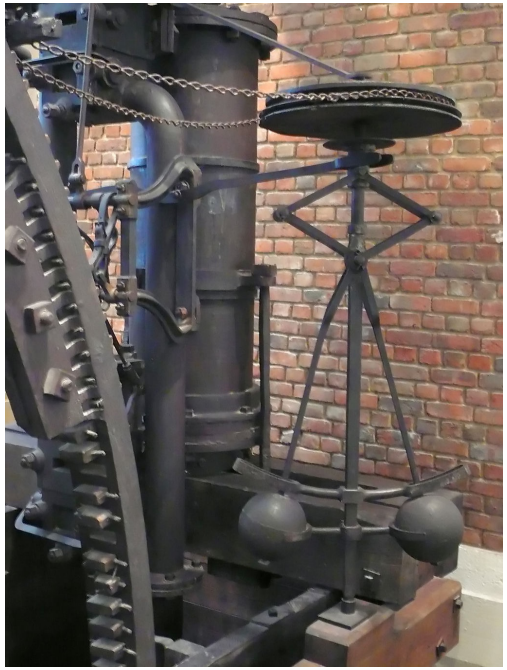


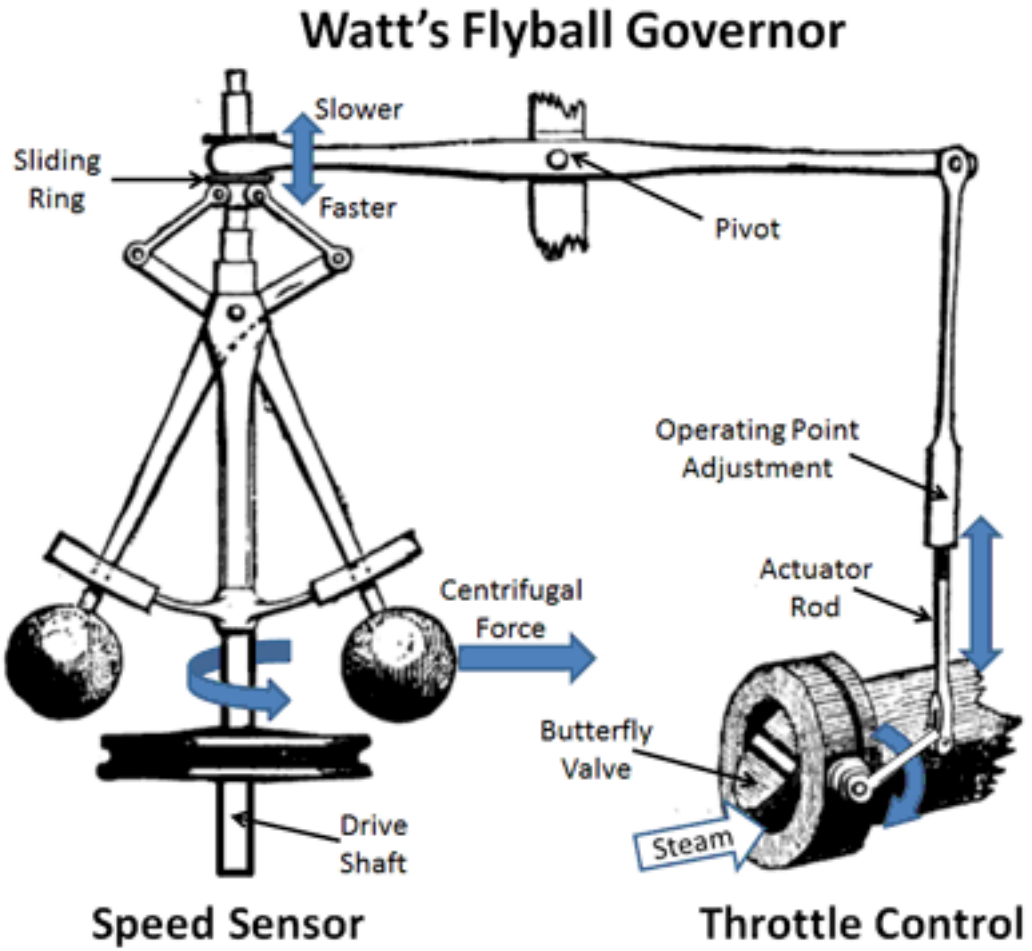
- Steam engine

fly-ball governor

- Industrial Revolution (1760~1840)

Mechanical feedback mechanism





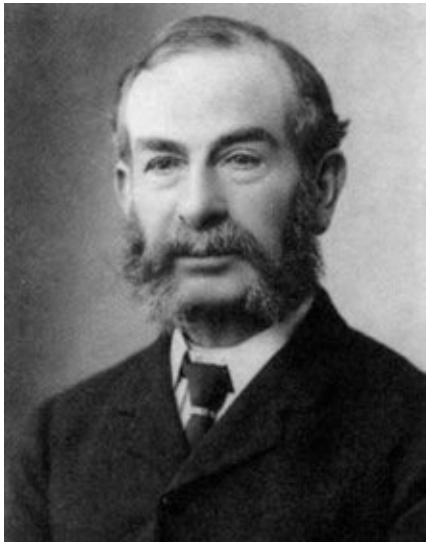
Mechanical feedback mechanism

- James Clerk Maxwell

"On governors", 1868

- Edward John Routh

Adams Prize, 1877



Electrical feedback mechanism

- Harold Stephen Black, 1929

Bell Telephone Laboratories, US

- Long-distance telephone

(negative) feedback amplifier

Electrical feedback mechanism

- Harry Nyquist

Bell Telephone Laboratories, US

"Regeneration theory", 1932

- Hendrik Wade Bode

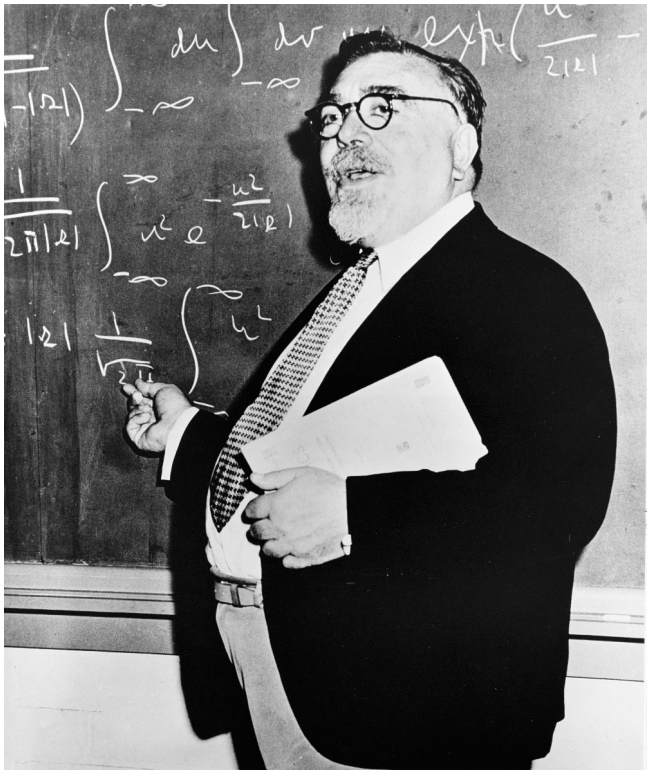
Bell Telephone Laboratories, US

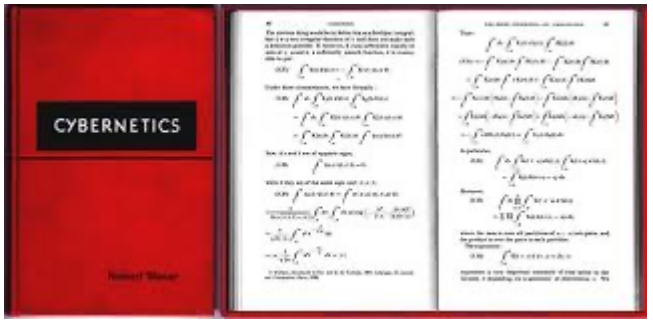
"Network Analysis &
Feedback Amplifier Design", 1945

Cybernetics

- Norbert Wiener, US
- WWII, *servomechanism*
- *"Cybernetics:*

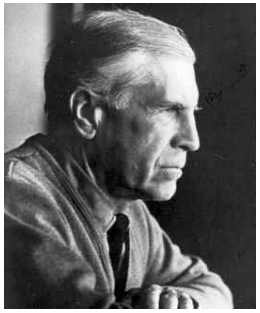
Or Control and Communication in the Animal and the Machine", 1948





Modern control theory

1950s~60s

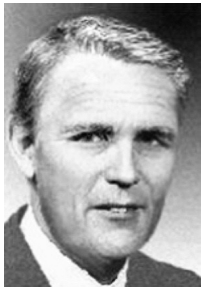


Lev Pontryagin
(1908-1988)

Pontryagin's Maximum Principle (1956)

Richard Bellman
(1920-1984)

Principle of Optimality (1957)



Rudolf E. Kalman
(1930-2016)

State space & Kalman filter (1960)

1970s

W. Murray Wonham
(1934-)

Linear geometric control

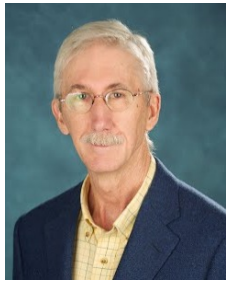
A. Stephen Morse
(1939-)

Linear geometric control

George Zames
(1934-1997)

Robust control

1980~90s



Bruce Francis
(1947-2018)

Optimal control

Alberto Isidori
(1942-)

Nonlinear control

Peter Ramadge
(1954-)

Supervisory control

In this course you will learn

1. State models
2. Laplace transform, transfer function
3. Stability
4. Feedback loop
5. Nyquist stability criterion
6. Bode plots and control design

Course information

- Format: Offline & online (on demand)
- Moodle: online material
- Website (slides and videos uploaded weekly):

https://www.control.eng.osaka-cu.ac.jp/teaching/classical-2022

- Grading:

Final test (100%); 60% to pass.

- Q & A:

Email (cai@omu.ac.jp) or Moodle

- Optional software: Matlab

Matlab

- State model
- Transfer function
- Laplace transform
- Stability analysis
- Nyquist plot
- Bode plots