EE160: Introduction to Control

Y. Wang

About the course:

This course is the basis for many courses in EE and CS including

- Circuit Design, Electronics
- Robotics
- Linear Systems, Stochastic Processes

and is very useful (but not mandatory) for understanding

- Applications in Machine Learning, AI, ...
- Network Algorithm, Communication, Wireless Networks
- Applications in Physics, Chemistry, Biology, ...

The course is highly recommended for all students in the field of engineering, mathematics, physics, and computer science, who want to develop a basic understanding of control.

About the course:

The course “Introduction to Control” provides an overview of control systems.

We cover：
scalar models
single-input-single-output (SISO) systems
basic concepts of linear control system design including PID control
basic ideas of modern controller design based on optimization including the linear-quadratic regulator

Moreover：
learn how to use the theory of this lecture in practical applications
Active participation in numerous smaller and bigger programming projects is required

Prerequisite courses
Linear Algebra； calculus; (maybe) signal processing

About the course:

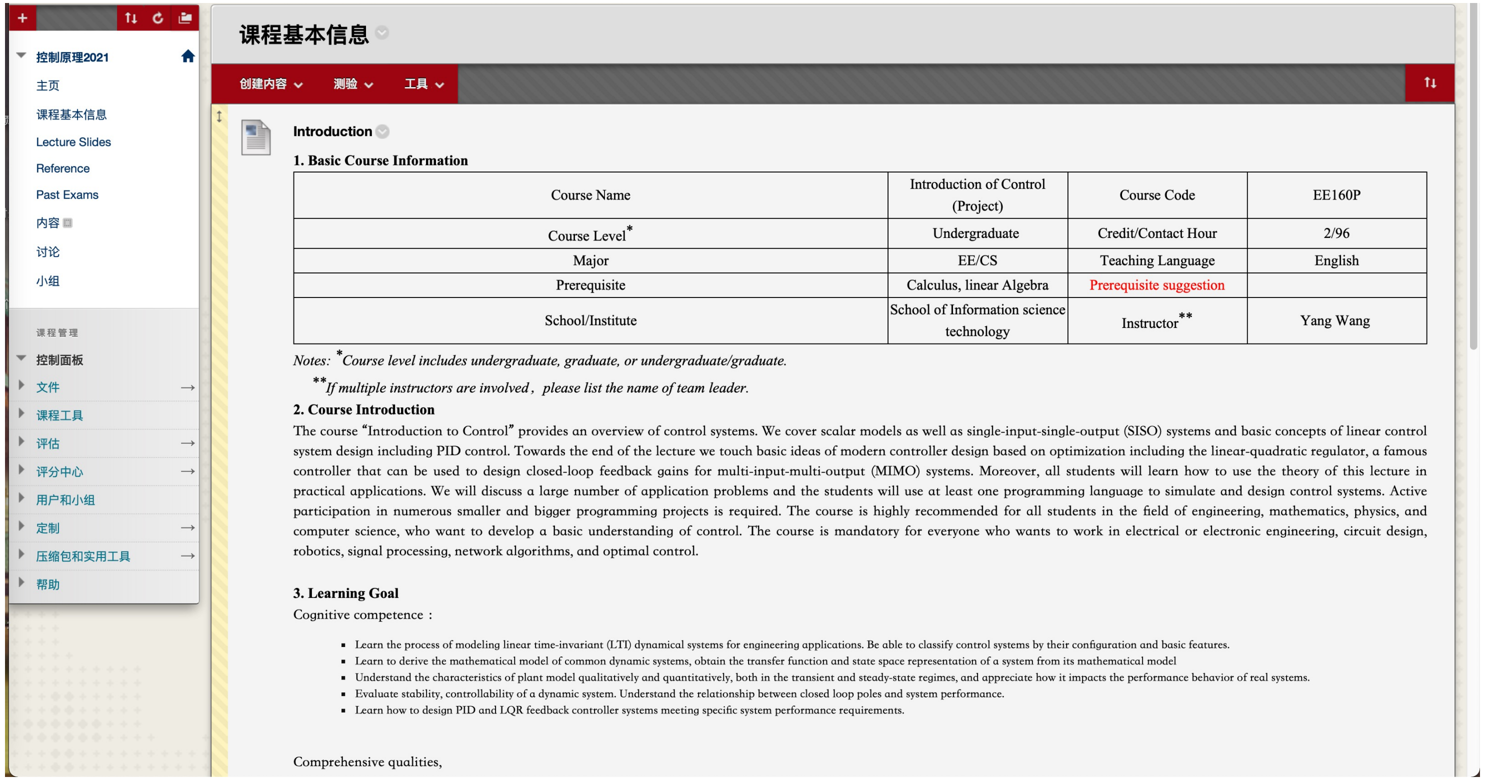
控制论是一门研究生命体、机器和组织的内部或彼此之间的控制和通信的科学。

——1948, Cybernetics, Norbert Wiener, 1894~1964

All contents will be consistent with the Lecture given by Prof. Boris Houska in Spring

About the course:

All information about the lecture, slides, news, announcements, exercises, tutorials, project requirements, code examples, animations, etc. at BlackBoard.



Very important: read and follow the lecture script!

About the course:

上海科技大学
ShanghaiTech University

Date and Location:
Week1-16, Tuesdays 10:15-11:45, Thursdays 10:15-11:45
Room: SIST, Room 1D-106
Exceptions will be announced in the lecture and on the Blackboard.

Office hour:
Wednesday 2:00pm-3:00pm @ 1D201.E
Please come to me ASAP if you encounter significant difficulties.I won’t bite.

TA：
张恒 zhangheng1@shanghaitech.edu.cn
潘宇琦 panyq@shanghaitech.edu.cn
贺贯齐 hegq@shanghaitech.edu.cn
余肖鹏 yuxp@shanghaitech.edu.cn

QQ group:

枫林飘渺、蔓蔓而歌
扫一扫二维码，加入群聊。
QQ

About the course:

Exercise & Homework:

There will be some in-class exercise, from time-to-time. (NOT GRADED)

There will be a few after-class homework, including some programming tasks.(GRADED with DEADLINE)

Note:

- Please bring pen and paper with you for each lecture.
- Please familiar yourself with one programming language, eg. Matlab, Julia, Python, C++ ...
- Please do the Homework by yourself.
- Please try to come to lecture even though you feel completely lost at certain time.

About the course:

Grading:

20% Homework + 40% Mid-term Exam(Around 8th week) +40% Final Exam(17th week)

Note:

Specific date will be announced latter

We will provide Q&A session before the exam

The exam questions will be similar to homework and in-class exercises

Please do the past exam to understand what I mean by “similar”.

The exam will be closed-book exam, but you are allowed to bring an A4 cheat sheet.

• About Project Course

One goal:
The EE160 Project is about the modeling, simulation, and control of a nonlinear system of your choice.

Two options:
1. Pick at least one of the application examples we recommended
2. Propose a control problem of your own choice.

Three tasks:
1. Proposal report (with reference):
    - form your team (<=3) and roughly break down the task
    - modeling and define control objective,
    - linearize your system and do open-loop simulation
2. Project report (5-10 pages)
    - design your control law and brief analysis
    - verify effectiveness of your control law
    - check the robustness of your algorithm
3. Presentation (with live simulation demonstrate)
    - problem formulation
    - solution
    - live simulation demonstration(play with tuning parameters)

There is only "Pass" or not "Pass" for the project.

OUTLINE

01 Early control: 300 B.C. -1900s

02 Classical control : 1900s-1960s

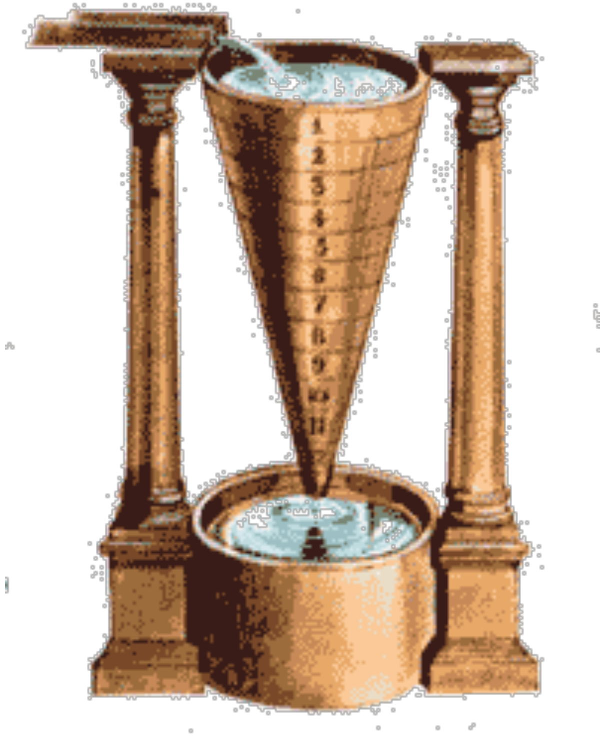
03 Modern control : 1960s-now?

Early control

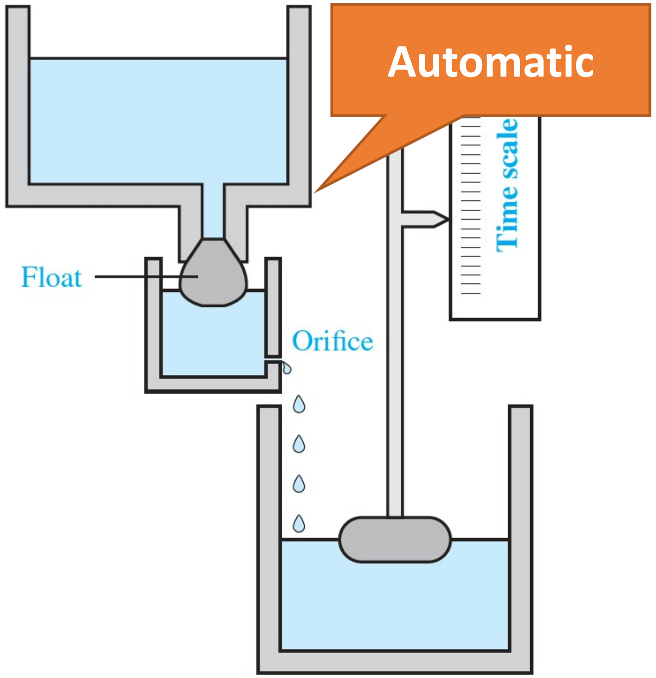
• Where the story begins…

- 1948, Cybernetics, Norbert Wiener, 1894~1964
- A long long time ago…

Described by Vitruvius and attributed to Ktesibios (Greece? Middle East? Egypt?), was used until the **17th century**.



Ancient Rome：270 B.C.



Water Clock

Rites of Zhou: 770 B.C.

Early Control

• What is a control system?

上海科技大学 ShanghaiTech University

DEFINITION : Wherever there is a system that **measures** something, **think** about how to appropriately react based on the measurement, and then **does something** to a dynamic plant based on its though process, it is likely using a form of control.

Examples:

Automated vehicles

Social, economic, and political systems

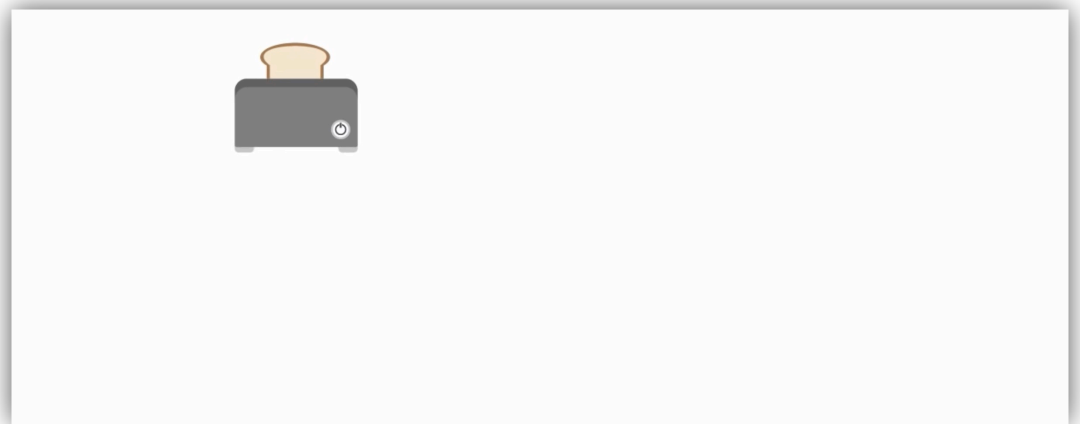
UAVs

Humanoid robots

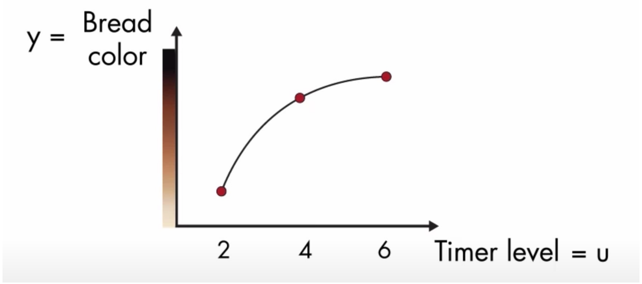
Electric power industry

Biomedical engineering

Open-loop Toaster



Toast based on Time (Plant model)



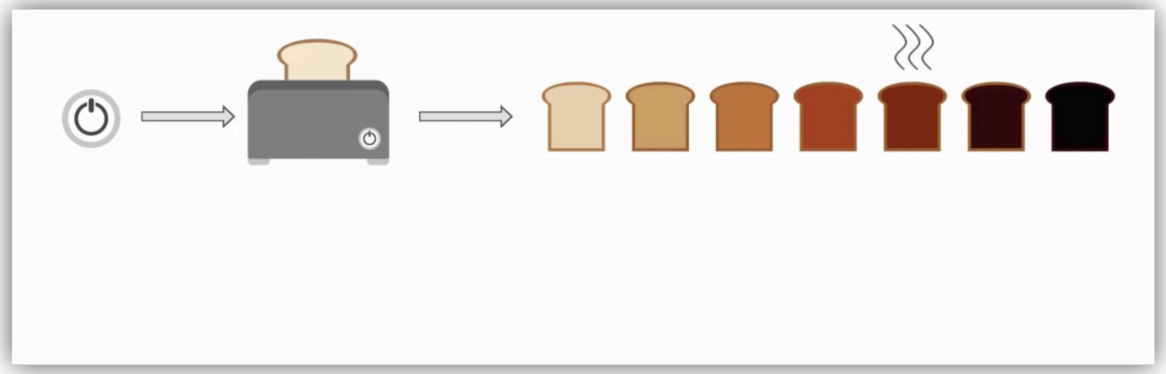
Problem: model change?

• Why feedback control system?

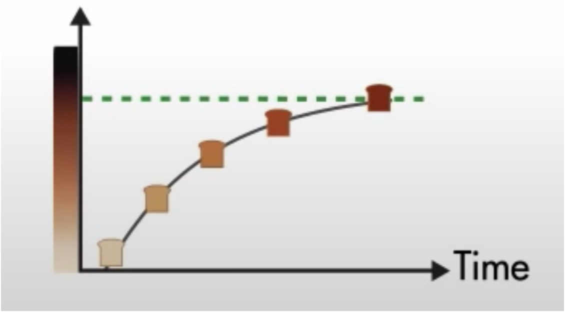
KEY FACTORS: Sense, Think and Do

Control system engineering is based on the foundations of **feedback theory**

Closed-loop Toaster



Toast based on Color (Error)

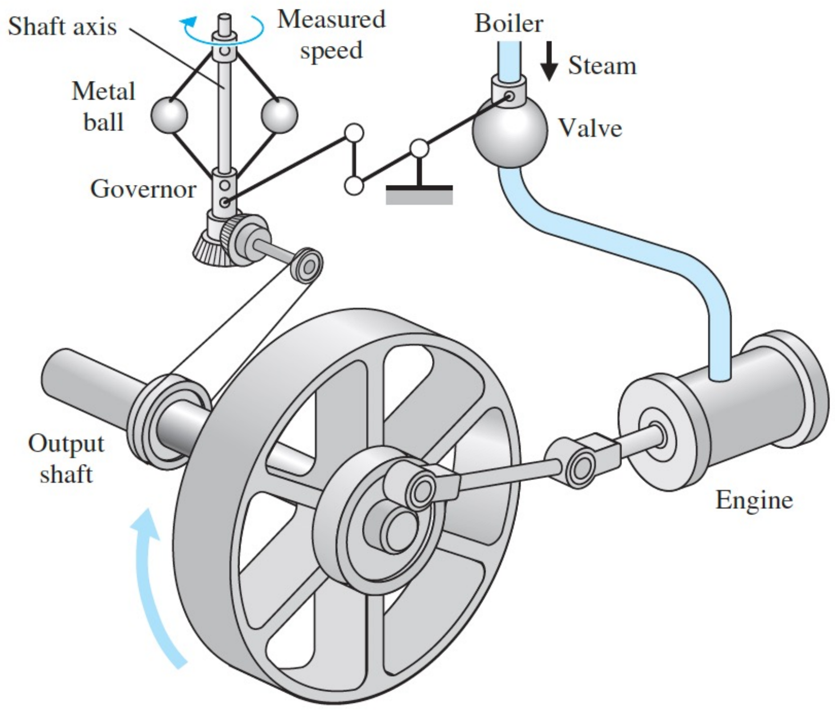


Human being acting as sensor and controller (decision maker) for a long long time and most engineering applications, Until….

Early Control

- 18th century

1769： James Watt's flyball governor



IF steam engine output shaft speed increases

↓

the ball weights rise and move away from the shaft axis

↓

the steam valve closes

↓

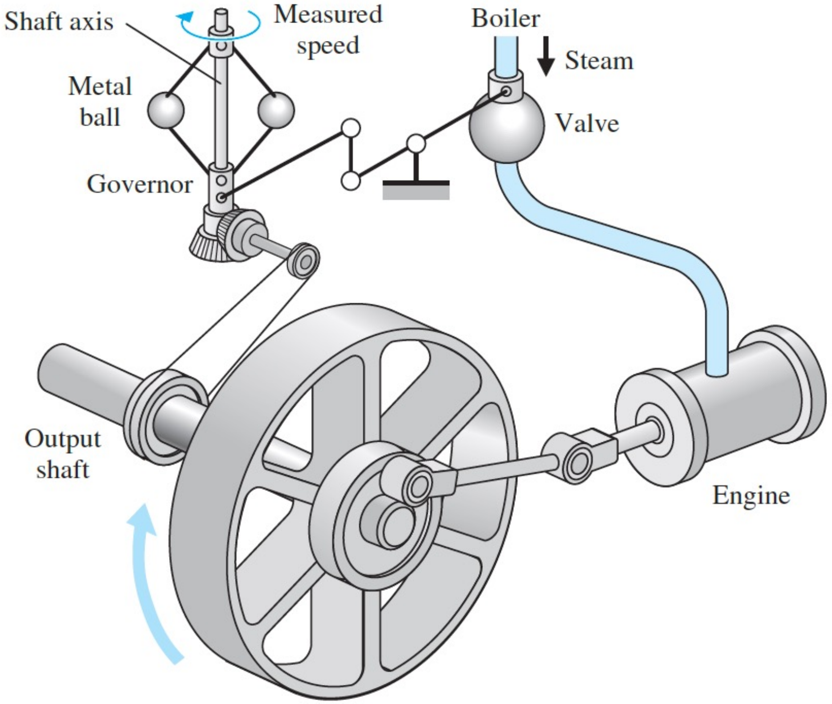
the engine slows down

The first technically automatic feedback controller

Early Control

• 18^{th} century

James Watt's flyball governor in 1769



IF steam engine output shaft speed decreases

↓

the ball weights fall and move close to the shaft axis

↓

the steam valve opens

↓

the engine speed up

The first technically automatic feedback controller

The first typical proportional controller

Early Control

- 19th century

James Watt’s flyball governor disadvantages:

- provided only proportional control and hence exact control of speed at only one operating condition
- it could operate only over a small speed range;
- it required careful maintenance

Improvements:

- William Siemens (1846)： integral

- Charles T. Porter (1858)： higher speeds
- Thomas Pickering (1862)： spring-loaded governors
- William Hartnell (1872)： smaller physical size

Mechanician

Here goes the mathematicians and physicists:

- Laplace 1785
- Lagrange 1788
- Fourier 1807
- Cauchy 1825

- J. C. Maxwell 1868 : "On Governors"

formulated a mathematical theory related to control theory using a differential equation model of a governor

OUTLINE

01 Early control: 300 B.C. -1900s

02 Classical control : 1900s-1960s

Early Control

- 19^{th} century

Concepts start to emerge…

- Modeling, Dynamic

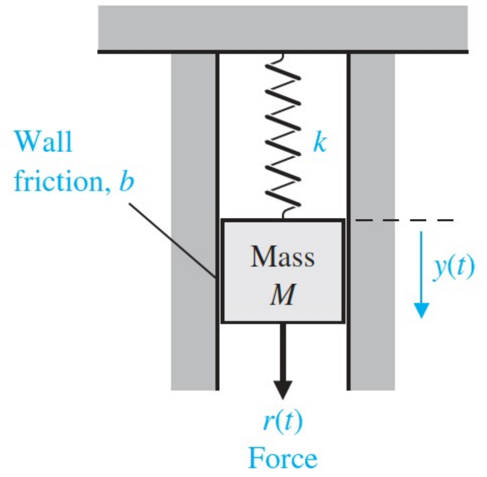
Electrical
Current i,Capacity C,Voltage v…

Fluid
Volume, pressure…

Differential equations

Mechanical
Force, mass, velocity, Position, friction…

Thermal
Temperature, Heat energy..



Utilizing Newton's second law yields:

$$M\frac{d^2y(t)}{dt^2} + b\frac{dy(t)}{dt} + ky(t) = r(t)$$

Next, I'm going to solving the equation…

。 。 。
Er, did you take your pills this morning?

Early Control

- 19th century

Concepts start to emerge…

- Modeling, Dynamic
- Frequency domain, transfer function

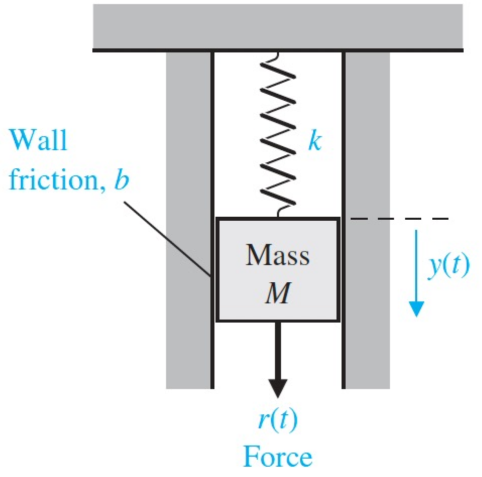
$$e^{-at} \to \frac{1}{s+a}$$

$$\sin(\omega t) \to \frac{\omega}{s^2+\omega^2}$$

Algebraic equations

$$\frac{d}{dt} \to s$$

$$1 \to \frac{1}{s}$$



Utilizing Newton's second law yields:

$$M\frac{d^2y(t)}{dt^2} + b\frac{dy(t)}{dt} + ky(t) = r(t)$$

Utilizing Laplace transform yields:

$$M\left(s^2Y(s) - sy(0^-) - \frac{dy}{dt}(0^-)\right) + b(sY(s) - y(0^-)) + kY(s) = R(s)$$

Transfer function:

$$T(s) = \frac{Y(s)}{R(s)} = \frac{1}{Ms^2+bs+k}$$

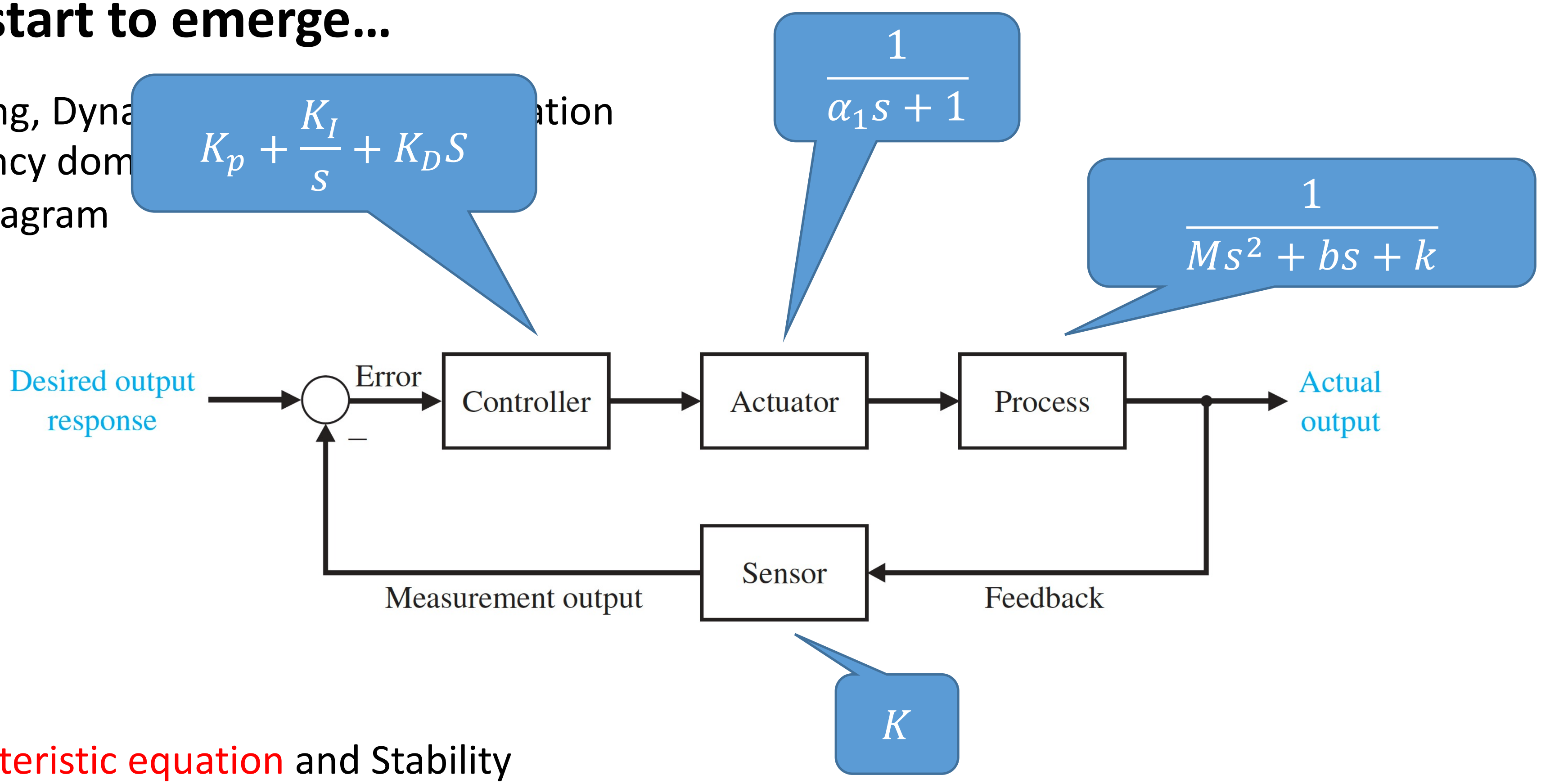
Early Control

• 19th century

上海科技大学 ShanghaiTech University

Concepts start to emerge…

- Modeling, Dyna ation
- Frequency dom
- Block diagram



- Characteristic equation and Stability

$$T(s) = \frac{Y(s)}{R(s)} = \frac{s^m + b_{m-1}s^{m-1} + \cdots + b_1 s + b_0}{s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0}$$

a system became unstable when the real part of a complex root became positive

Here comes the power of Money and Government…

- 1909 - 1929 sales of sensors and controller
  AT&T， Siemens， IBM…
- 1927, Harold S. Black from Bell Laboratories sketched a circuit for a negative feedback amplifier

> Then came the morning of Tuesday, August 2, 1927, when the concept of the negative feedback amplifier came to me in a flash while I was crossing the Hudson River on the Lackawanna Ferry, on my way to work.

Lackawanna Clock Tower, Hoboken Terminal, Hudson River, NY, New Jersey

上海科技大学 ShanghaiTech University

Here comes the power of Money and Government…

- 1909 - 1929 sales of sensors and controller
  AT&T， Siemens， IBM…
- 1927, Harold S. Black from Bell Laboratories sketched a circuit for a negative feedback amplifier
- 1932, Harry Nyquist
- 1936, Industrial Instruments and Regulators Committee
- 1940, Hendrik Bode: Bode diagram
- 1942, J.G. Ziegler and N.B. Nichols : Ziegler-Nichols tuning rules.

Here comes the power of Money and Government…

- 1909 - 1929 sales of sensors and controller
  AT&T， Siemens， IBM…
- 1927, Harold S. Black from Bell Laboratories sketched a circuit for a negative feedback amplifier
- 1932, Harry Nyquist
- 1936, Industrial Instruments and Regulators Committee
- 1940, Hendrik Bode: Bode diagram
- 1942, J.G. Ziegler and N.B. Nichols : Ziegler-Nichols tuning rules.
- 1943，Invention of anti-aircraft guns
  Two many names but a few organizations : MIT-EE, Bell Lab, MIT-Radiation Lab
- 1948，Walter Evans : Root Locus!

Classical control technique established!

OUTLINE

01 Early control: 300 B.C. -1900s

02 Classical control : 1900s-1960s

03 Modern control : 1960s-now?

Here comes the power of Money and Government…

- 1909 - 1929 sales of sensors and controller
  AT&T， Siemens， IBM…
- 1927, Harold S. Black from Bell Laboratories sketched a circuit for a negative feedback amplifier
- 1932, Harry Nyquist
- 1936, Industrial Instruments and Regulators Committee
- 1940, Hendrik Bode: Bode diagram
- 1942, J.G. Ziegler and N.B. Nichols : Ziegler-Nichols tuning rules.
- 1943，Invention of anti-aircraft guns
  Two many names but a few organizations : MIT-EE, Bell Lab, MIT-Radiation Lab

Big news is Time domain analysis starts to wake up!

- 1948，Walter Evans : Root Locus!

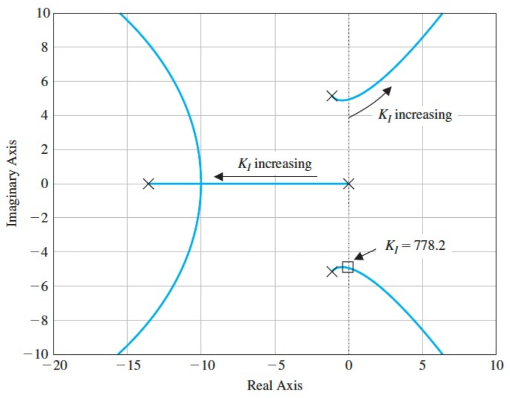
Classical control technique established!

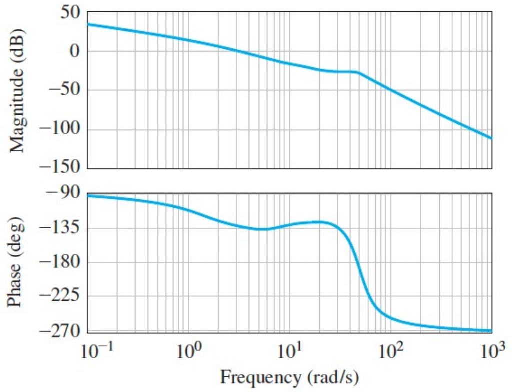
What do we have…

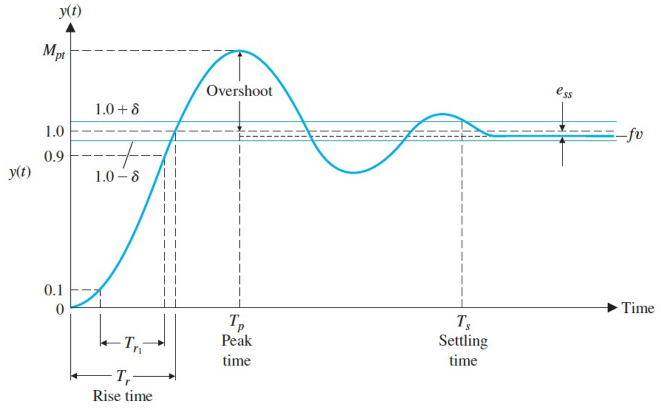
frequency response	
Routh-Hurwitz Nyquist Bode Nichols Root locus …	bandwidth cut frequency gain margin phase margins Poles & Zeros Stability …

A link needed

time response	
Laplace inverse differential equation	rise time, percentage overshoot steady-state error damping





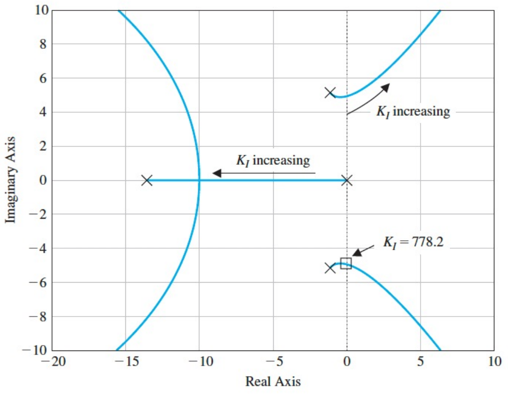


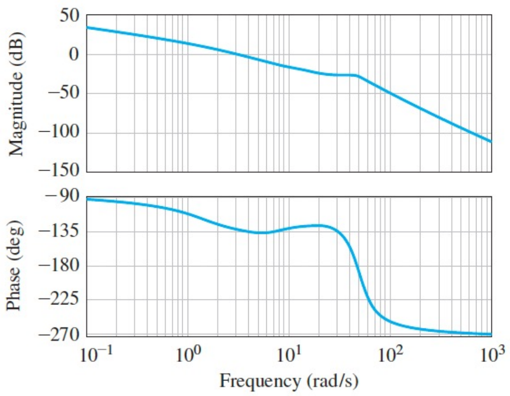
What do we have…

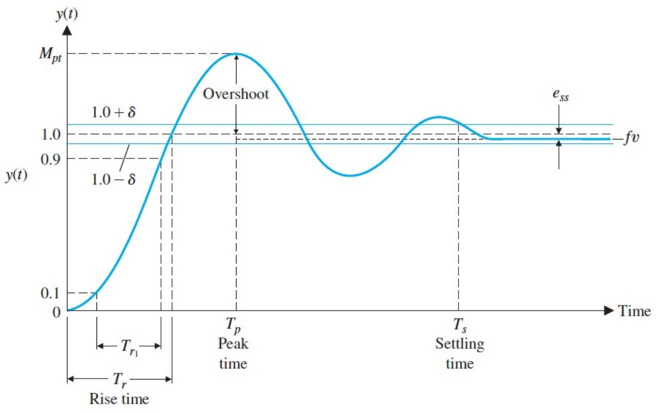
frequency response	
Routh-Hurwitz Nyquist Bode Nichols Root locus …	bandwidth cut frequency gain margin phase margins Poles & Zeros Stability …

State Space!

time response	
differential equation	rise time, percentage overshoot steady-state error damping







Modern control

• Cold war period

Warning： computer scientists are watching you.

- 1960s Kalman: State-space approach

- Later on

  Digital and discrete-time control   Nonlinear control
  Model predictive control   Robust control   Adaptive control
  NN based control   Sliding-mode control   Fuzzy control
  …   …   …

  The control community grow so fast and gets out of control.

- Future

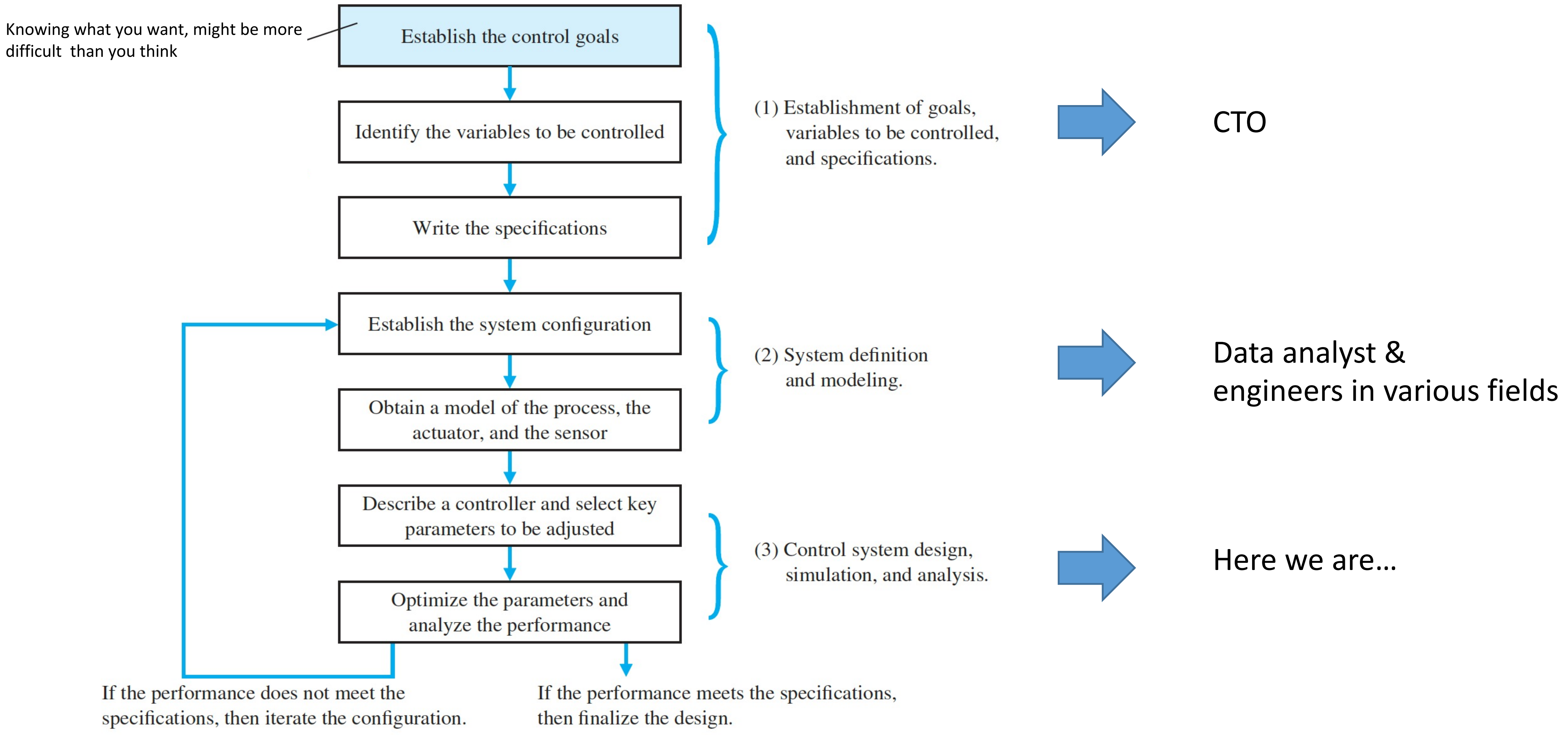
  Intelligent : AI
  Interconnection
  Integrated
  …

Recall your toaster

- Know your taste preference after a while? ML
- Guess your taste preference based on your …? Big data
- Upload your preference to the cloud? IoT
- Judge your health condition and mood based on todays' choice? AI

…

The control system design process



Thanks!

ShanghaiTech Automation and Robotics Center · 上海科技大学自动化与机器人中心

STAR CENTER