Typical Real-Time Applications

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Real time systems provide us with important services

- When we drive,
  - Control the engine and brakes of car and regulate traffic lights.
- When we fly,
  - Schedule and monitor takeoff and landing of planes.
  - Make it fly, maintain the flight path and keep it out of harm's way.
- When we are sick,
  - Monitor and regulate our blood pressure and heart beats.
- When we are will,
  - Entertain us with electronic games.
- Unlike PCs and workstations that runs non-realtime applications, such as editor and network browser, they are hidden from our view.

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Real-Time and Embedded Systems

- A *real-time* system must deliver services in a timely manner
  - *Not* necessarily fast, but must meet some timing deadline
- An *embedded* system is hidden from view within a larger system
- Many real-time and embedded systems exist, often without the awareness of their users
  - Washing machine, photocopier, mobile phone, car, aircraft, industrial plant, microwave oven, toothbrush, medical devices, etc.
- Must be able to validate real-time systems for correctness
  - Some embedded real-time systems are safety critical – i.e. if they do not complete on a timely basis, serious consequences result
  - Bugs in embedded real-time systems are often difficult or expensive to fix

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- This chapter will discuss several representative classes of real- time and embedded system:
  - Digital process control
  - Higher-level command and control
  - Tracking and signal processing
  - Real-time databases
  - Telephony and multimedia

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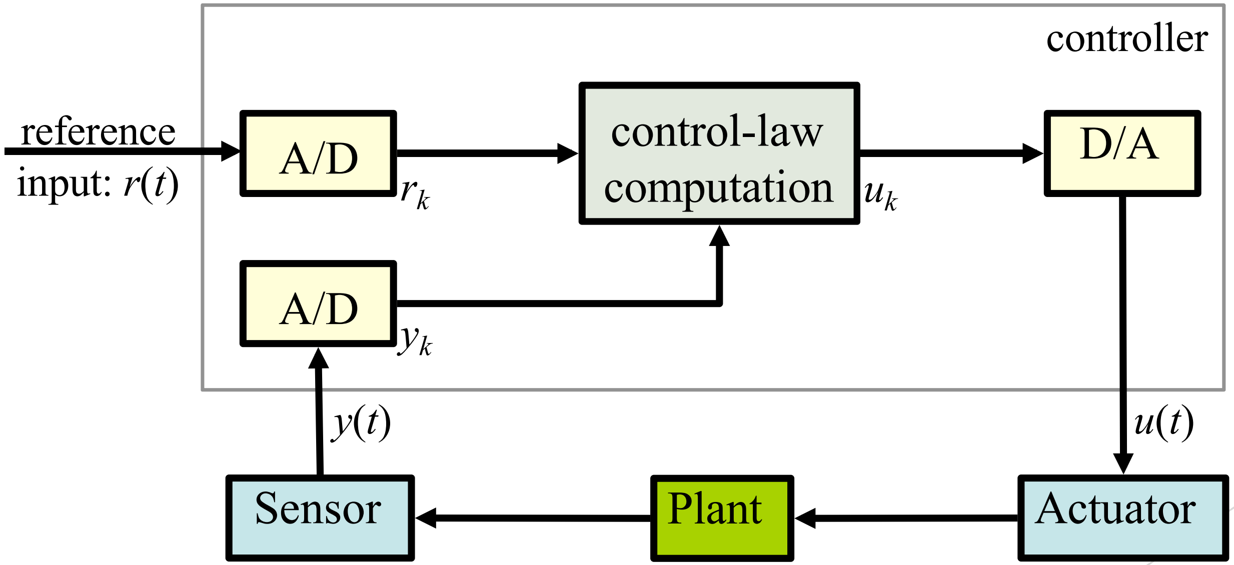
Digital Process Control

Digital Control - Sampled Data System

- Controlling some device (the “plant”) using an actuator, based on sampled sensor data
  - $y(t)$ is the measured state of the plant
  - $r(t)$ is the desired state of the plant
  - Calculate control output $u(t)$ as a function of $y(t)$, $r(t)$



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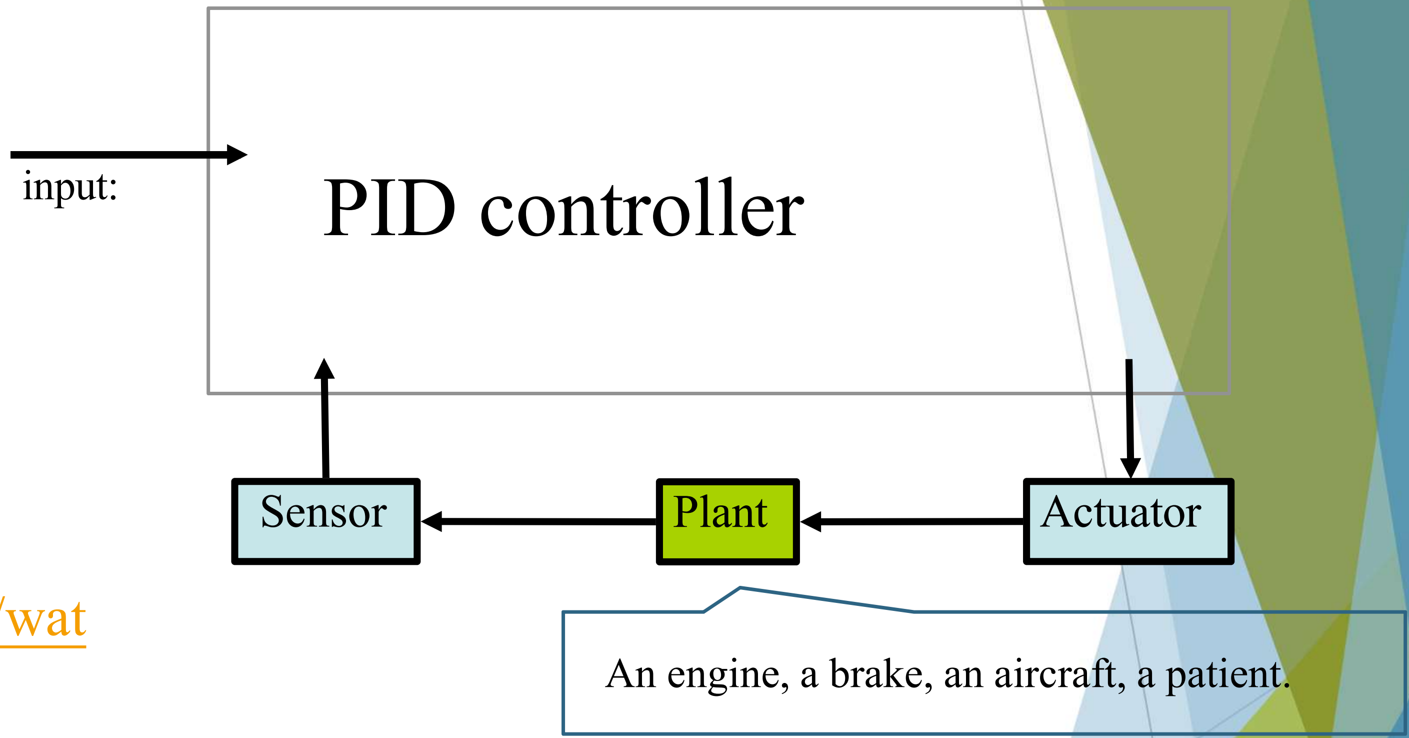
PID (Proportional, Integral, and Derivative) controller

- Proportional control:
- Integral control:
- Derivative control:
- K_p, K_i and K_d are proportional constants, chosen at design time
- 參考補充資料 PID

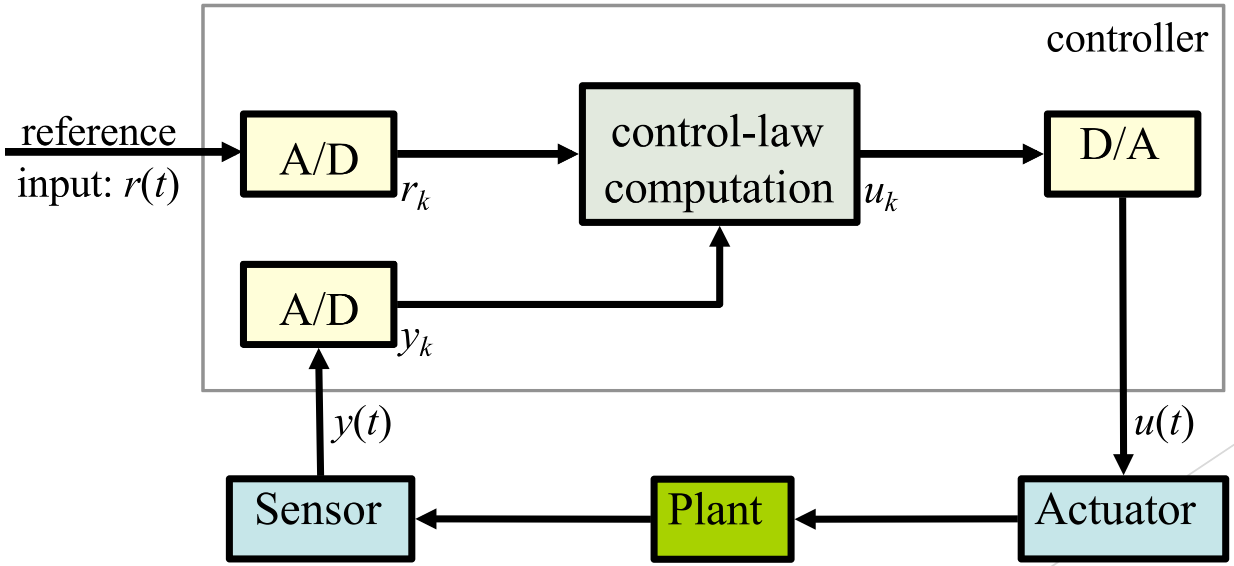
https://www.youtube.com/watch?v=wkfEZmsQqiA



$$u(k) = K_p e(k) + K_i \sum_{n=0}^{k} e(n) + K_d \left(e(k) - e(k-1)\right)$$

Pseduo-code for the digital controller

set timer to interrupt periodically with period T ;
at each timer interrupt, do
    do analog-to-digital conversion to get y;
    compute control output u;
    output u and do digital-to-analog conversion;
end do;



Effective control of the plant depends on

- Correct control law computation
- Correct reference input
- Accurate sensor measurements

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The accuracy of the sensor measurements

- Resolution of the sampled data (i.e. bits per sample)
- Timing of the clock interrupts (i.e. samples per second, 1/T)

Two Factors of Selection of Sampling Period

- Perceived responsiveness of the overall system
  - The plant and the controller
  - The operator (a driver or a pilot): 1/10 秒(a tenth of a second)
- The dynamic behavior of the plant.
  - Disk drive controller.
  - The plant is the arm of a disk

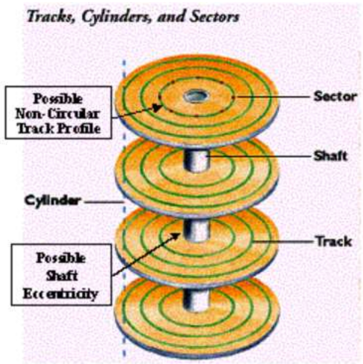

Fig 2. Spindle Shaft and Disk Platters

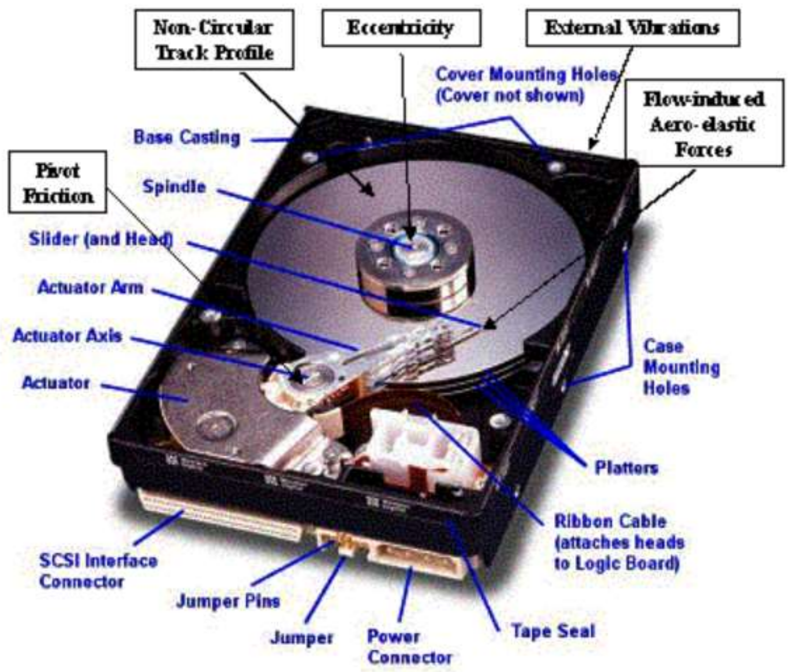

Fig 1. Industrial Hard-Disk Drives (HDD)

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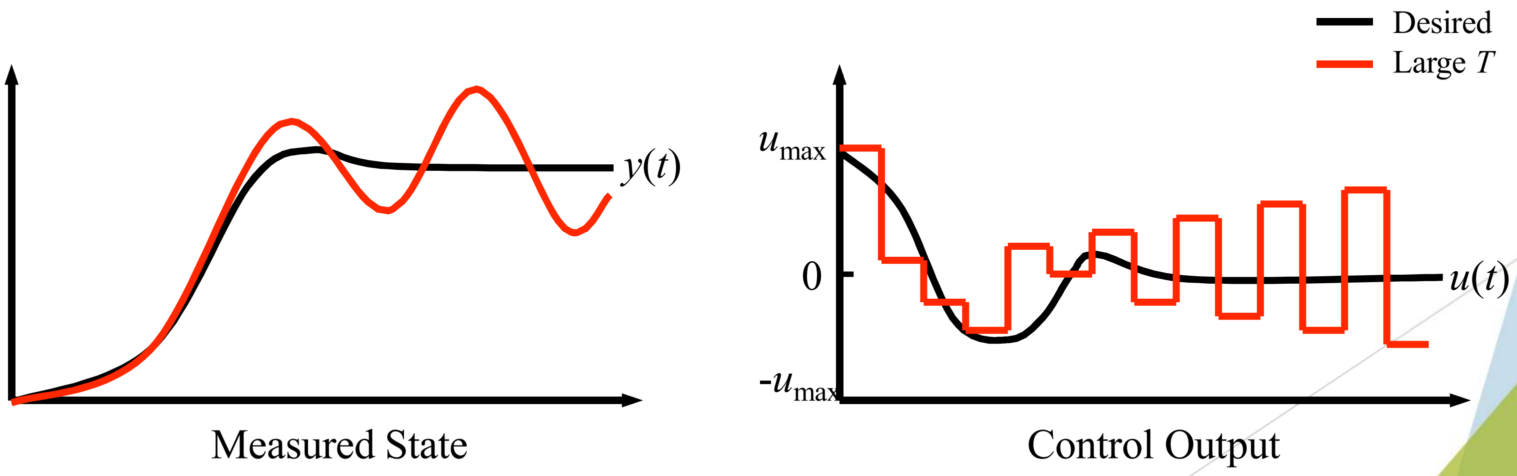
Selection of Sampling Period

- The time T between any two consecutive measurement of y(t), r(t) is the sampling period
  - Small T better approximates the analogue behavior
  - Large T means less processor-time demands
  - Must achieve a compromise
- If T is too large, oscillation will result as the system tries to adapt



How to choose sampling period?

- Rise time – the amount of time that the plant takes to reach some small neighbor hood around the final state in response to a step change in the reference input
- If R is the rise time, and T is the period, a good rule of thumb is that the ratio $10 \leq R/T \leq 20$
- Must be chosen correctly, and accurately implemented to ensure stability

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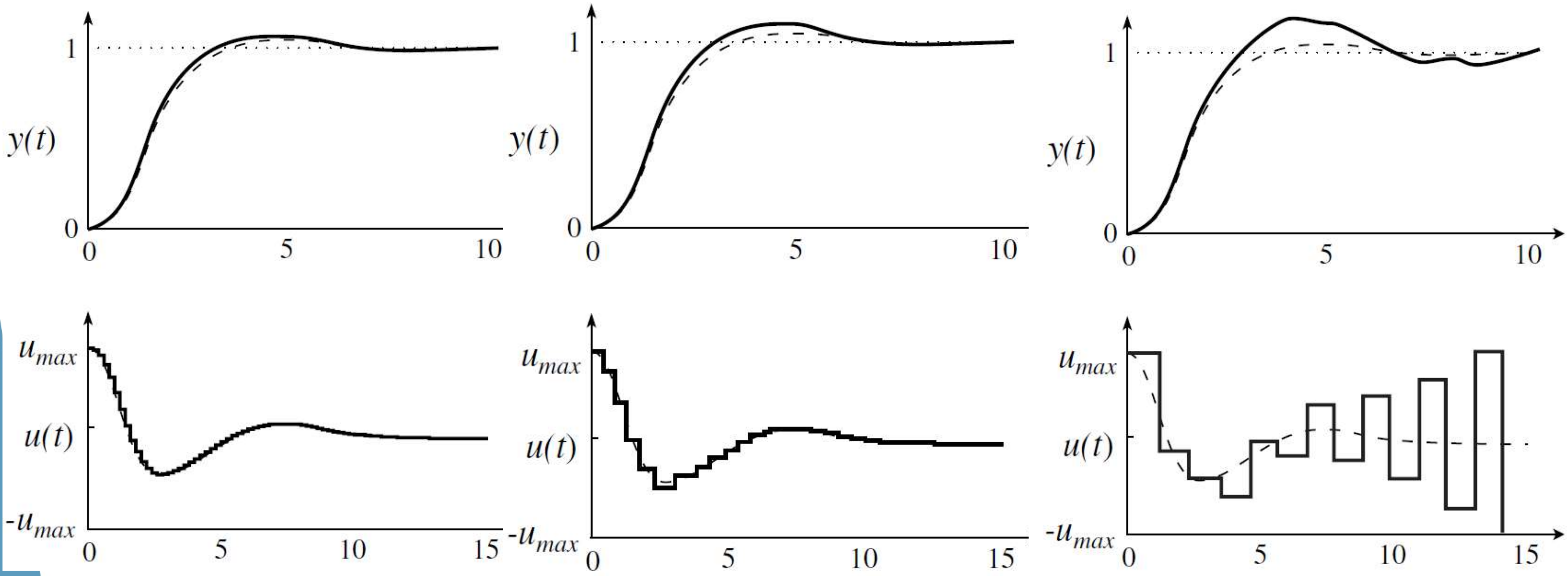
Effects of sampling period, Rise time is about 2.5



(a) T = R/20

(b) T = R/10

(c) T = R/5

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Multi-rate systems

- The state of a plant is defined by multiple state variables.
  - The rotation speed, temperature, etc.
- Monitored by multiple sensors and controlled by multiple actuators,
- Different state variables have different dynamics.
  - Ex: the rotation speed of a engine changes faster than its temperature, the required sampling rate for RPM (rotation per minute) control is higher than that for the temperature control.
- To achieve smooth response, each of which require different sampling periods → Multi-rate system
  - Need to run multiple control loops at once, accurately
  - Usually best to have the sampling periods for the different degrees of freedom related in a harmonic way

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Example: Helicopter Flight Control

補充資料 https://www.youtube.com/watch?v=KEVN0E3FjsU

- Do the following in each 1/180-second cycle:
- Validate sensor data and select data source; on failure reconfigure the system
- Do the following 30-Hz avionics tasks, each once every 6 cycles:
  - Keyboard input and mode selection
  - Data normalization and coordinate transformation
  - Tracking reference update
- Do the following 30-Hz computations, each once every 6 cycles
  - Control laws of the outer pitch-control loop
  - Control laws of the outer roll-control loop
  - Control laws of the outer yaw- and collective-control loop
- Do each of the following 90-Hz computations once every 2 cycles, using outputs produced by the 30-Hz computations
  - Control laws of the inner pitch-control loop
  - Control laws of the inner roll- and collective-control loop
- Compute the control laws of the inner yaw-control loop, using outputs from the 90-Hz computations
- Output commands to control surfaces
- Carry out built-in-test

https://howthingsfly.si.edu/flight-dynamics/roll-pitch-and-yaw

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Summary

- Digital controllers make three assumptions:
  - Sensor data give accurate estimates of the state-variables being monitored and controlled - noiseless
  - The sensor data gives the state of the plant – usually must compute plant state from measured values
  - All parameters representing the dynamics of the plant are known
- When any of the simplifying assumptions is not valid, the simple feedback loop no longer suffices.

```
set timer to interrupt periodically with period T;
at each timer interrupt, do
    do analog-to-digital conversion to get y;
    compute control output u;
    output u and do digital-to-analog conversion;
end do;
```

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More complex Control-Law Computations

- If any of these assumptions are not valid, a digital controller must include a model of the correct system behavior
  - Estimate actual state based on noisy measurement each iteration of the control loop
  - Use estimated plant state instead of measured state to derive control output
  - Often requires complex calculation, modelling

```
set timer to interrupt periodically with period T;
at each clock interrupt, do
    sample and digitize sensor readings to get measured values;
    compute control output from measured and state-variable values;
    convert control output to analog form;
    estimate and update plant parameters;
    compute and update state variables;
end do;
```

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Two examples to show the state update is needed.

- Deadbeat control.
  - A discrete-time control scheme that has no continuous-time equivalence is deadbeat control.

$$u_k = \alpha \sum_{i=0}^{k} (r_i - y_i) + \sum_{i=0}^{k} \beta_i x_i$$

  - Kalman filtering is a commonly used means to improved the accuracy of measurements and to estimate model parameters in the presence of noise and uncertainty.

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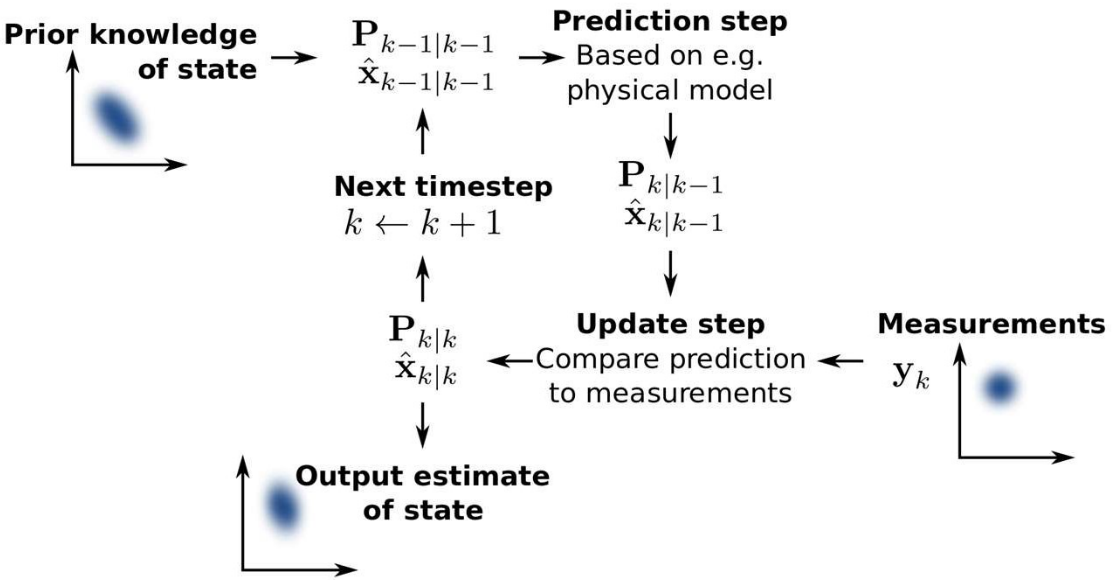
Kalman Filter. 補充資料 https://www.youtube.com/watch?v=mwn8xhgNpFY



$$\tilde{x}_k = \tilde{x}_{k-1} + K_k(y_k - \tilde{x}_{k-1})$$

$$K_k = \frac{P_k}{{\sigma_k}^2 + P_k}$$

ı and P_k is the variance of the estimation

$$P_k = E[(\tilde{x}_k - x)^2] = (1 - K_{k-1})P_{k-1}$$

$$\tilde{\mathbf{x}}_k = \tilde{\mathbf{x}}_{k-1} + \mathbf{K}_k(\mathbf{y}_k - \mathbf{A}\tilde{\mathbf{x}}_{k-1})$$

The computation in each sampling period involves a few matrix multiplication and additions and one matrix inversion.

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Outline

- Digital process control
- Higher-level command and control
- Tracking and signal processing
- Real-time databases
- Telephony and multimedia