Dr. Norbert Cheung's Lecture Series

Level 5 Topic no: 9

Digital PID Controller

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3. Variations of PID control
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Reference: Katsuhiko Ogata, "Discrete Time Control Systems", Prentice Hall

1. The Digital Control Platform

Due to the advancement of digital electronics, most controllers nowadays are based on digital control rather than analogue control.

Digital Controllers needs to convert a continuous time signal into discrete digital form before it can implement its control algorithm.

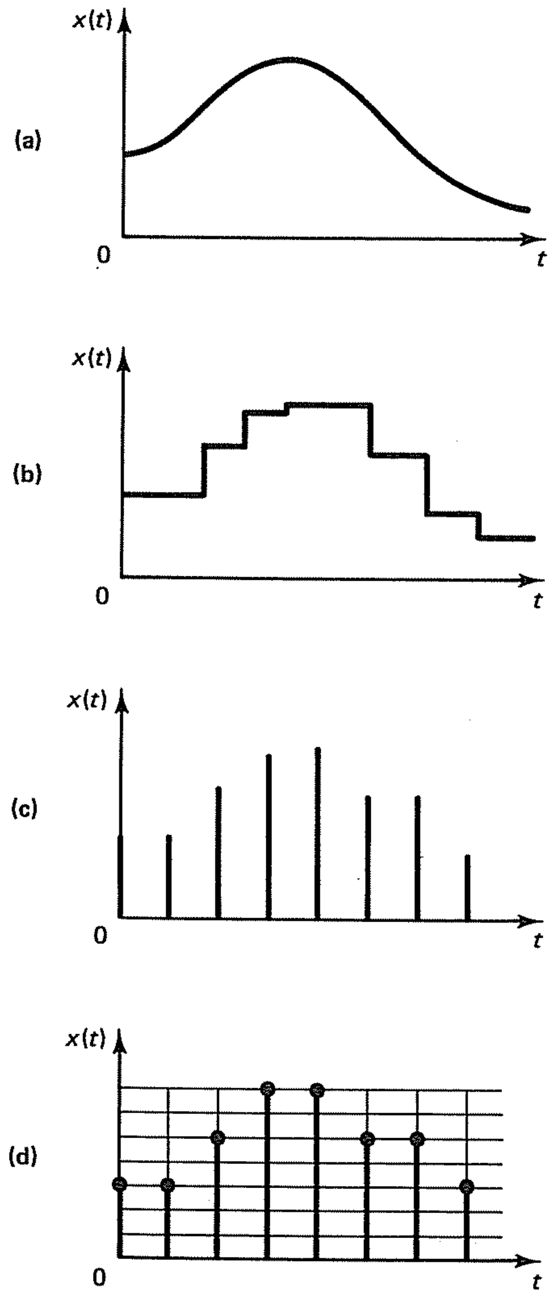


Figure 1–1 (a) Continuous-time analog signal; (b) continuous-time quantized signal; (c) sampled-data signal; (d) digital signal.

From a continuous waveform, the signal needs to be transformed into a zero-order hold signal (with a sample and hold circuitry), after that, the voltage is sampled and converted into a digital number.

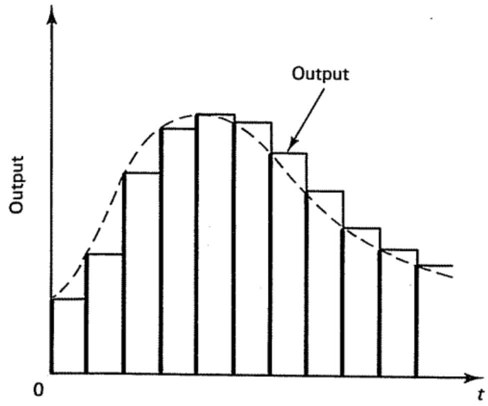


Figure 1–19 Output from a zero-order hold.

However, it must be noted that, there will be a time lag in this process. Therefore our sample frequency must be fast enough to take into account of this delay.

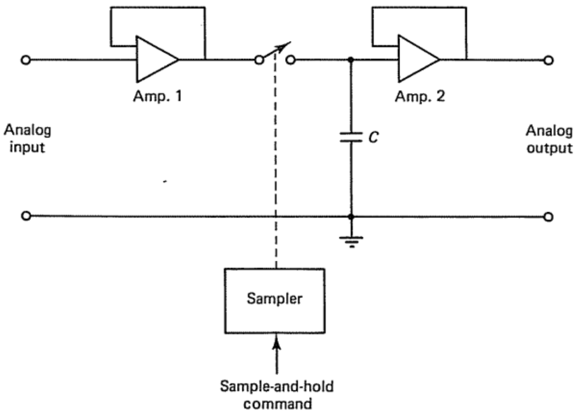
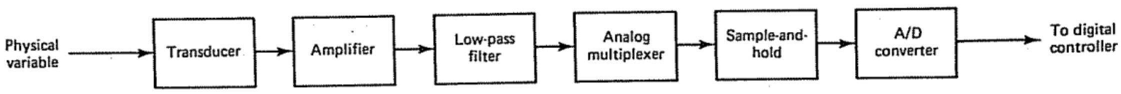


Figure above shows a typical zero-order hold circuit. It is commonly used in all analogue acquisition cards.



A proper analogue acquisition system for control MUST consists of all of the above blocks.

According to Nyquist Theorem, the minimum sampling frequency must be higher than twice the frequency response of the plant (i.e. motor) under control.

However, in practice, the sampling frequency must be at least 5-10 times higher.

The resolution must also correspond to the resolution requirement of the plant under control.

Below shows the effect of low resolution/sampling of a two axis Computerized Numerical Control (CNC) machine, when it is executing a 2 dimension profile.

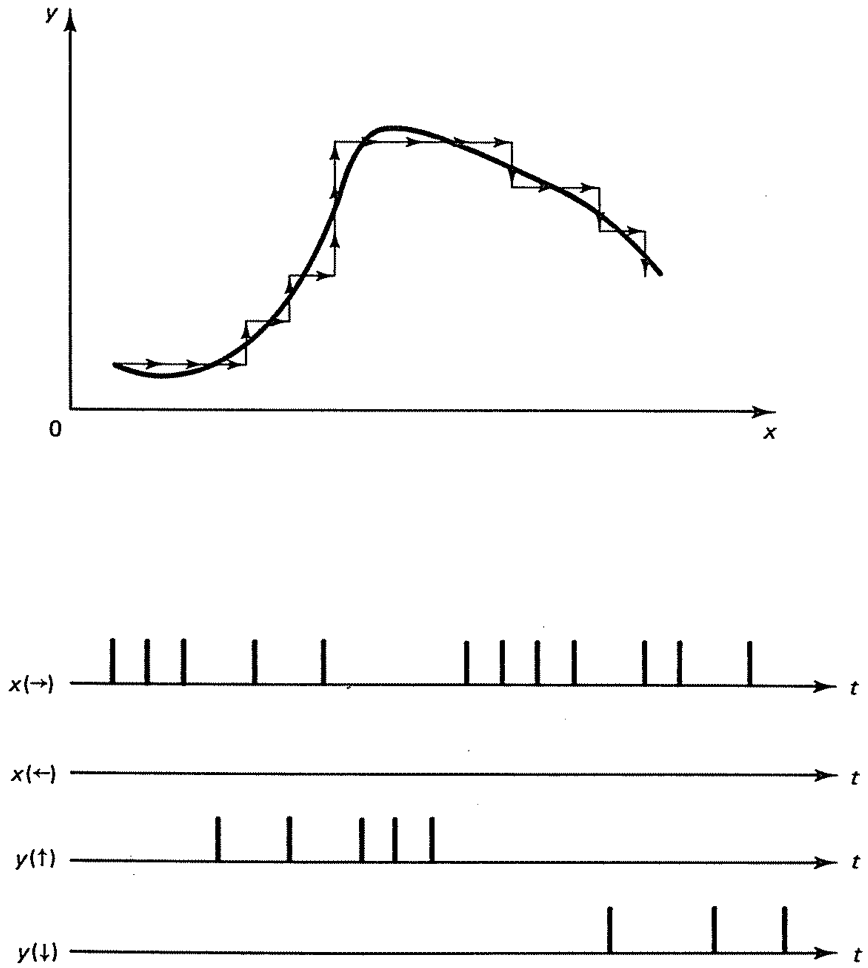


Figure 1–5 Profile approximation by a numerically controlled milling machine.

Figure below shows the typical block diagram of a digital motion control system.

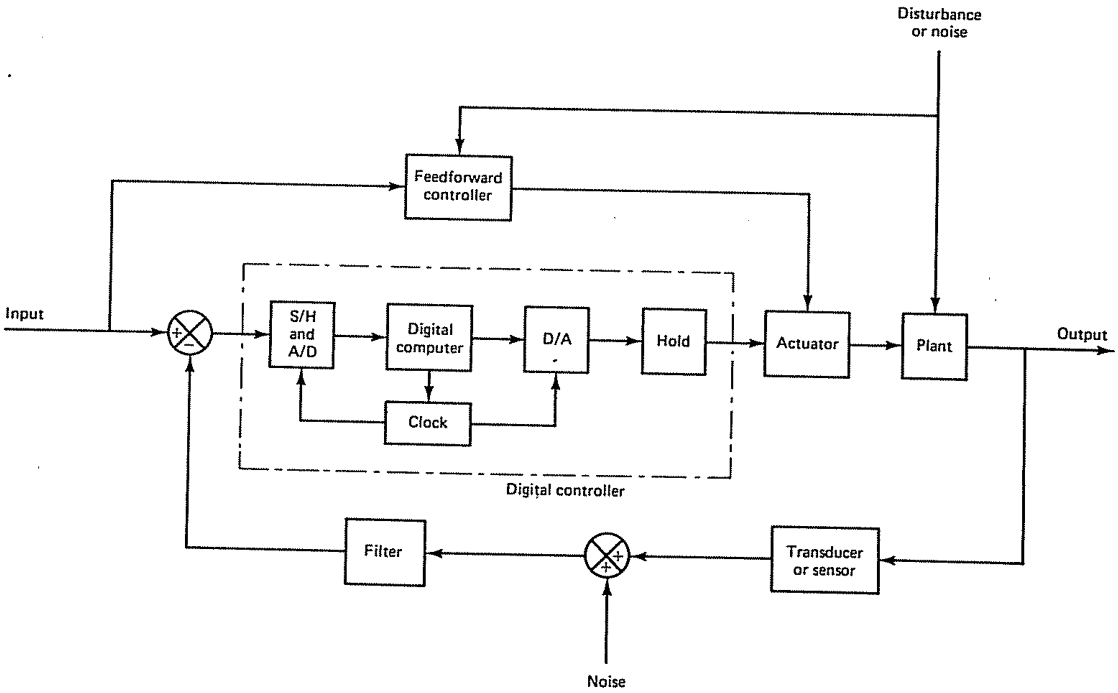


Figure 1–2 Block diagram of a digital control system.

Figure below shows the processing signals of the system.

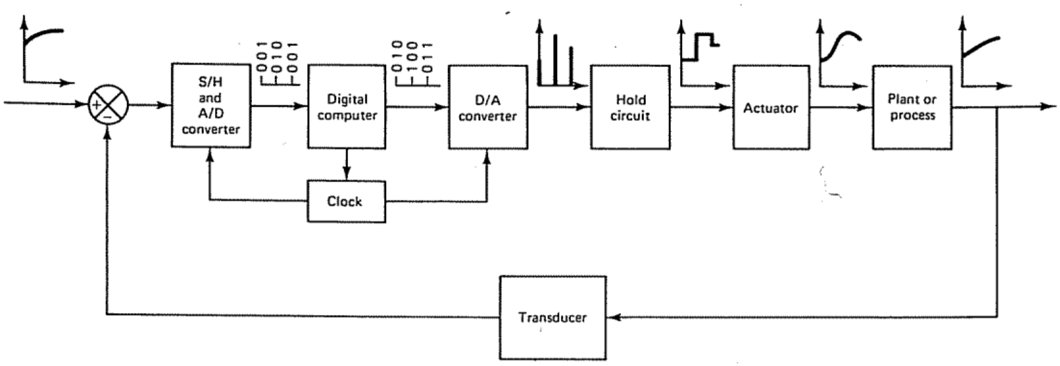


Figure 1–3 Block diagram of a digital control system showing signals in binary or graphic form.

If more than one channel of analogue input signal is required for the control algorithm, the system may need simultaneous sample and hold.

Figure below shows a digital controller applied to a motion control system.

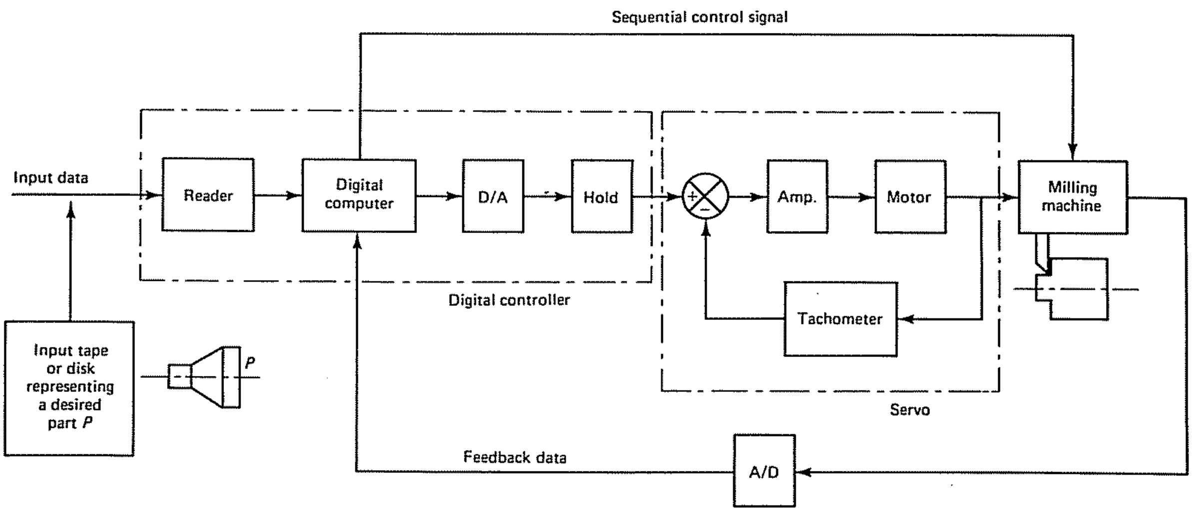


Figure 1–4 Block diagram of a numerically controlled milling machine.

3. The Basic PID Control Algorithm

Almost 80% of all controllers in the world use PID control, or variations of PID control. It is the easiest to use, and most easy to understand and visualize.

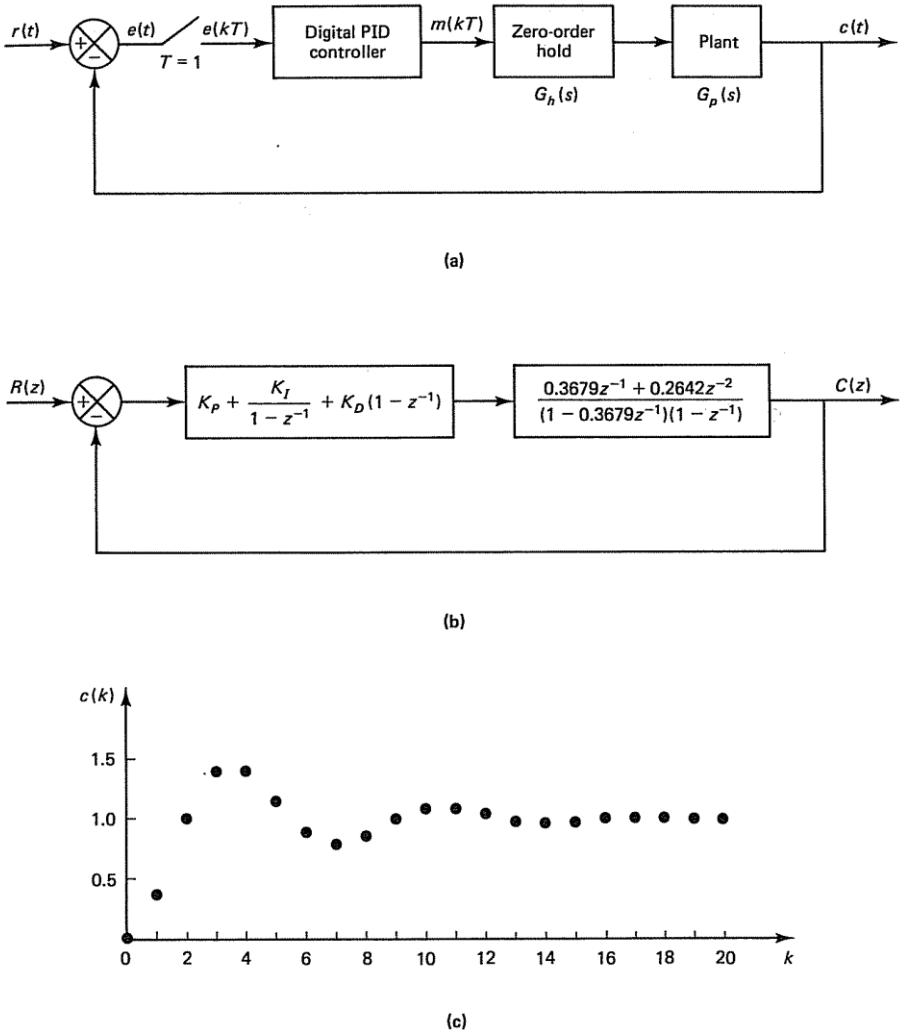
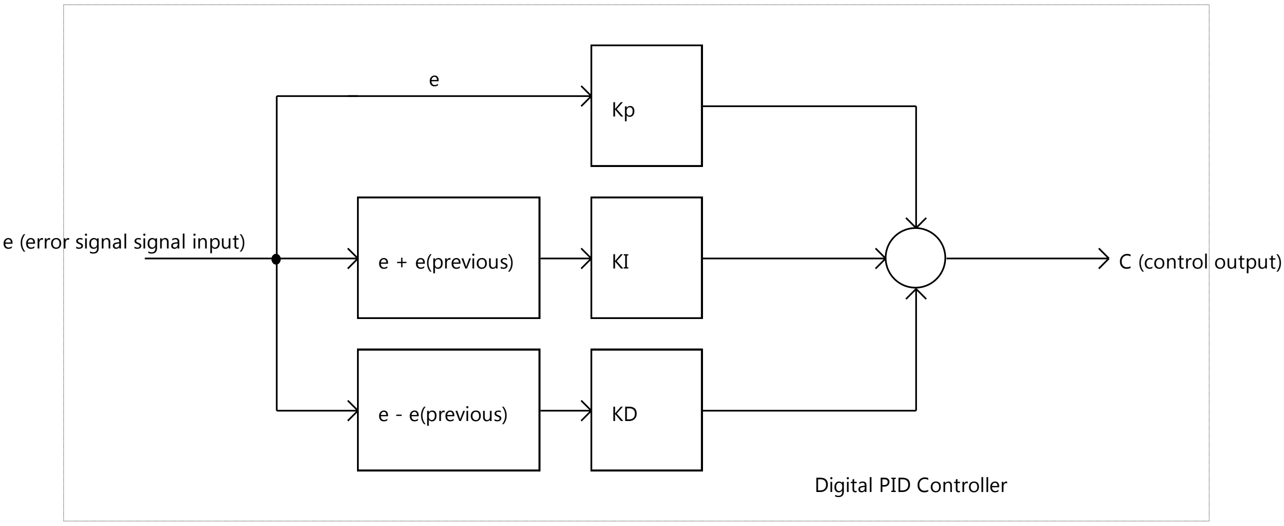


Figure 3–39 (a) Block diagram of a control sytem; (b) equivalent block diagram; (c) plot of the output $c(k)$ vs. k when the input is a unit step and when $K_P = 1$, $K_I = 0$, and $K_D = 0$.

It is easier to manipulate sampled data systems using Z Transform. The transformation technique is similar to Laplace transform, students should make reference to digital control books on this topic.

The Digital PID controller can be represented by the diagram below.



Features:

- Need to tune PID values to get optimum results.
- Tuning one value will affect the other
- P is for the main feedback function
- I is to overcome the steady state error
- D is to improve the dynamic response.
- Over tune P will lead to oscillation
- Over tune I will lead to instability
- Over tune D will lead to noise increase
- PID is only good for a fixed system with a fixed load
- The disturbance should be small and limited

<u>Ziegler-Nichols Tuning for PID controller</u>

This is the simplest, quite systematic way of tuning the PID controller. The main advantage: there is no requirement on the plant model, or any knowledge of the plant. However, in most cases, Ziegler-Nichols Tuning will not lead to the most optimum tuning parameters. There are two types of Ziegler Nichols tuning methods:

1. Transient Response Method
2. Stability Limit Method

Transient Response Method

1. Measure the open loop step response of the plant
2. Obtain L and R
3. Calculate the P, I, and D values according to the table below.

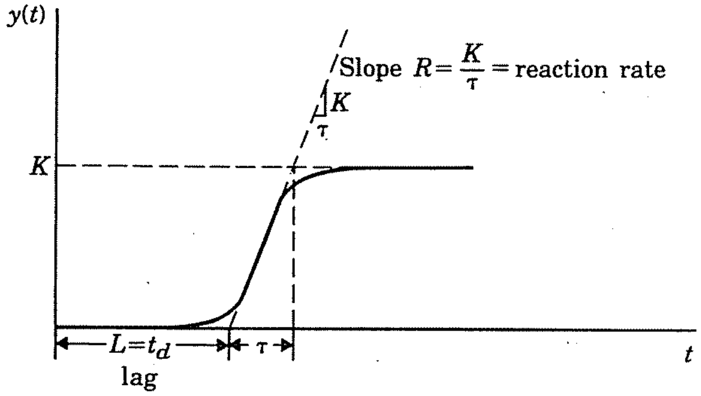


Figure 5.30 Process open-loop step response.

Table 5.2 Ziegler-Nichols tuning parameters using transient response.

	K_p	T_I	T_D
P	$1/RL$		
PI	$0.9/RL$	$3L$	
PID	$1.2/RL$	$2L$	$0.5L$

Stability Limit Method

1. Switch off I and D, increase P until it oscillates.
2. The P gain (K_u) and the oscillation period (P_u) are recorded
3. Calculate P, I, and D from the table below

Table 5.3 Ziegler-Nichols tuning parameters using stability limit.

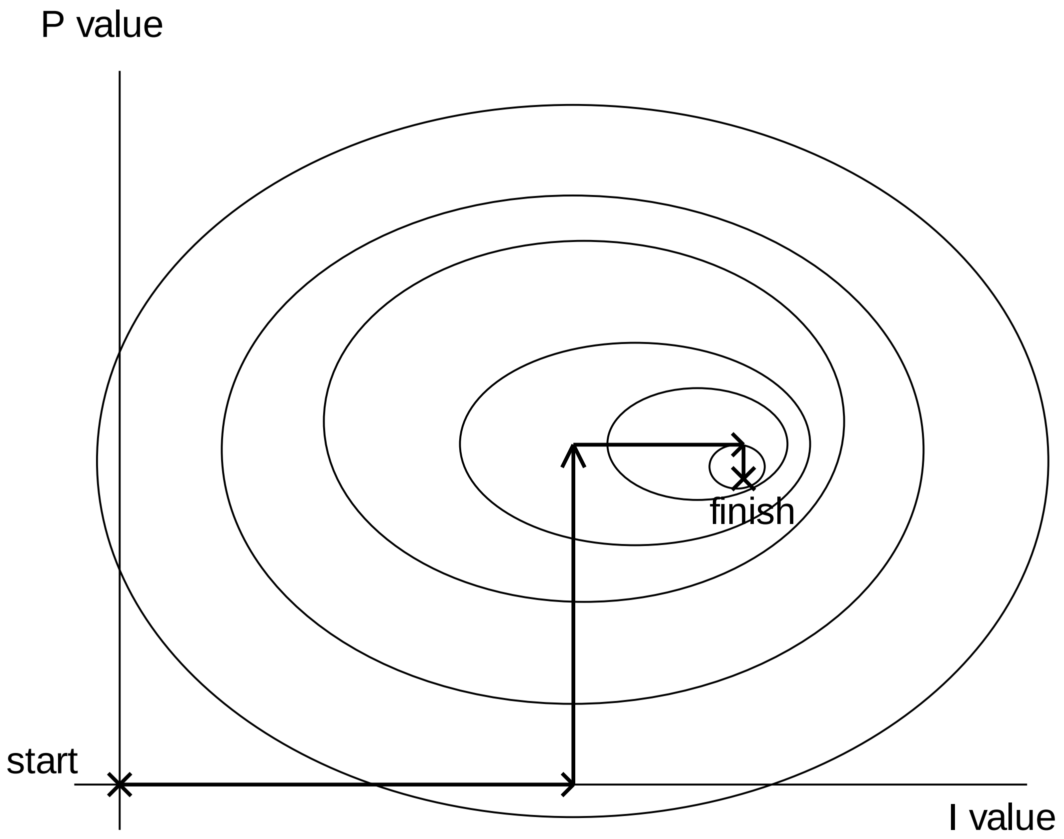
	K_p	T_I	T_D
P	$0.5K_u$		
PI	$0.45K_u$	$P_u/1.2$	
PID	$0.6K_u$	$P_u/2$	$P_u/8$

4. Variations of PID Control

To improve the basic performance of PID control, numerous "additives" are added to improve its performance.

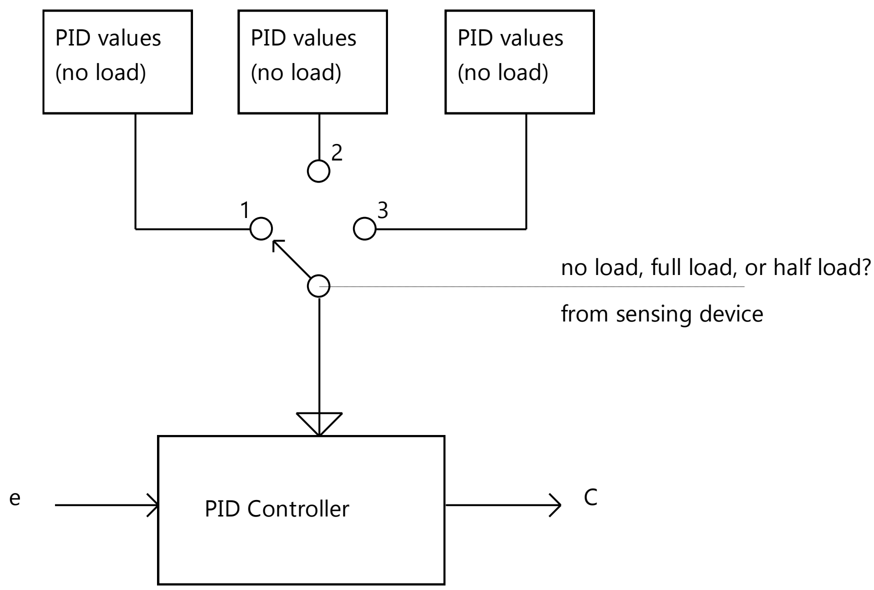
Automatic tuning of parameters – the auto-tuning method

- Normally useful for tuning of two parameters only. (e.g. P and I)
- Based on a profile search algorithm
- The user must define a performance index before auto tune
- Only useful for repetitive operation with fixed load
- May not tune to an optimum point (the local minimum problem)



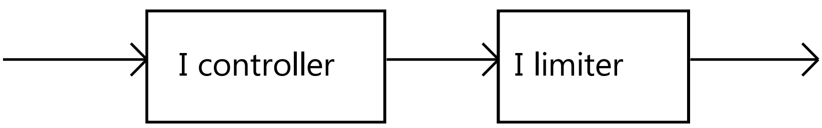
Gain Scheduling

- For predictable condition changing and predictable timing
- Under discrete operation environment (e.g. pick and place robots)
- Use a different set of PID values for different situation
- Care should be taking when changing the PID values



Integrator Anti-Windup

- To prevent integrator to accumulate to large a value
- To set a limit in the I value so that it will not be instable
- Suitable in systems when there is an occasion large error
- Most useful for trajectory following of large profile



5. Implementing PID in DC motor servo system

- Use cascade control
- Select appropriate sampling frequencies
- Assume that the inner loop is stabilized when executing outer loop control
- Use PI control only
- Apply appropriate low pass filtering
- Pay attention to sensor noise

Typical block diagram of a 3-loop cascade SISO system:

6. Control Terminologies

MIMO and SISO systems	
Control Model	
Control Simulation	
Model based Control Development	
Global Stability	
Performance Index	
System Robustness	
External Disturbance	

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