Chapter 5: Systems Synthesis

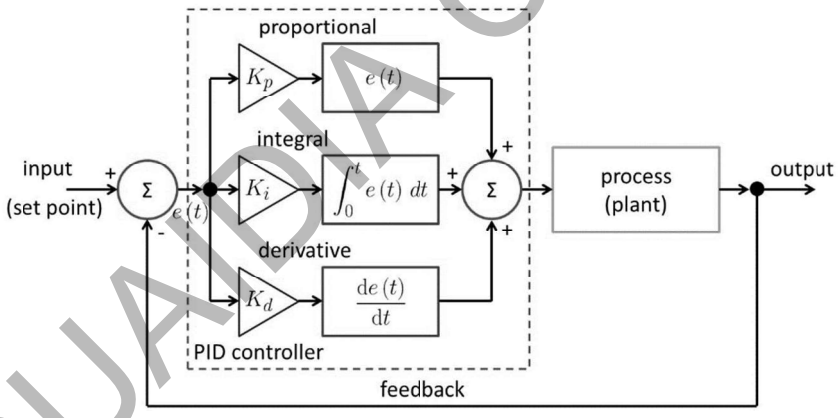
1 - Introduction

System synthesis in automatic control refers to the systematic procedure of designing a control system so that the resulting closed-loop behavior satisfies predefined specifications. These specifications typically include stability, transient response, steady-state accuracy, and robustness against disturbances and parameter variations. Unlike system analysis, which focuses on predicting the behavior of a given system, synthesis focuses on determining the appropriate controller structure and parameters to achieve the desired performance.

With the development of control theory, several synthesis methods have been introduced, ranging from classical techniques based on transfer functions and frequency-domain analysis to modern approaches using state-space modeling, optimal control, and robust control theory. Each method provides tools suited to different types of systems and design constraints.

2 – PID Controller:

follow a desired reference accurately and stably.



The control law is:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de(t)}{dt}$$

In Laplace domain:

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s$$

SOUAIDIA CHOUAIB

Effect of PID on system performance

Parameter	Rise Time	Overshoot	Steady-State Error	Stability
Increase K_p	↓	↑	↓	↓
Increase K_i	↓	↑	→ 0	↓
Increase K_d	~	↓	~	↑

- **Increase** K_p: Faster response, but more overshoot.
- **Increase** K_i: Eliminates offset, but may cause oscillations.
- **Increase** K_d: Damping, reduces overshoot, improves stability.

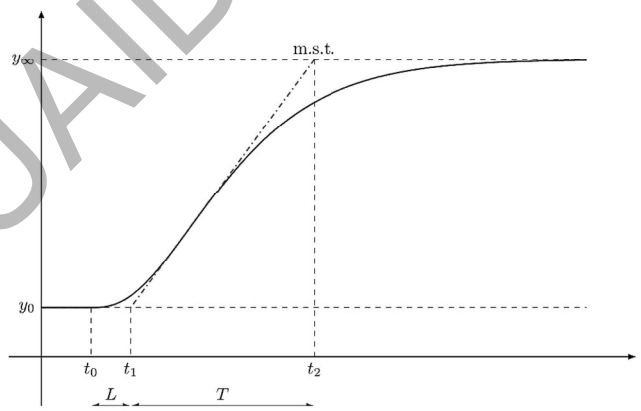
Tuning the PID Controller (Finding Kp, Ki, Kd)

Method	Approach	Use Case
Manual Tuning	Adjust parameters based on step response observation.	Simple systems, initial tuning.
Ziegler-Nichols	Find ultimate gain (K_u) and oscillation period (P_u), use formulas.	When process model is unknown.
Pole placement	Use feedback to "move" the open-loop poles to pre-selected desirable locations in the complex plane.	if and only if the system is completely controllable.

Ziegler-Nichols:

$$G_c(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) = K_p + \frac{K_i}{s} + K_d s$$

A. Step Response Method (Process Reaction Curve)



1. Apply a **unit step input** to the open-loop system.
2. Obtain an **S-shaped step response**.
3. Determine:
   - **L** = delay time $L = t_1 - t_0$
   - **T** = time constant $T = t_2 - t_1$
   - **K** = gain constant $K = y_\infty - y_0$
4. Use Z-N tuning formulas.

SOUAIDIA CHOUAIB

Tuning Formulas

Controller	K_p	T_i	T_d
P	$\frac{T}{K \cdot L}$	-	-
PI	$\frac{0.9T}{K \cdot L}$	$3.33L$	-
PID	$\frac{1.2T}{K \cdot L}$	$2L$	$0.5L$

B. Ultimate Gain Method (Closed-Loop Method)

1- Set controller to **P-only** mode:
   - $T_i = \infty, T_d = 0$
2- Increase K_p until:
   - Output shows **sustained oscillations**
3- Record:
   - **Ultimate gain** K_u
   - **Ultimate period** P_u

Tuning Formulas

Controller	K_p	K_i	K_d
P	$0.5K_u$	-	-
PI	$0.45K_u$	$1.2K_p/T_u$	-
PID	$0.6K_u$	$2K_p/T_u$	$K_pT_u/8$

SOUAIDIA CHOUAIB