Summary of Control Task

• Identify variables to control
• Identify any disturbances
• Identify what inputs can be manipulated
• Choose sensor(s) – ideally for all controlled variables
• Choose actuator(s)
• Power conditioning
• Logic
• Tuning and stability analysis
Closed-Loop Feedback Control

A standard closed-loop control diagram:

**Plant** – any physical system to be controlled  
**Controller** – can generate inputs to the plant to achieve a desired objective  
**Sensor** – means by which plant output is transformed to feedback information
Effect of Closing the Loop

• Advantages:
  – Provides for disturbance rejection
  – Reduces sensitivity to parameter variations
  – Use error signal for dynamic tracking
  – Enhance accuracy, extend bandwidth, etc.

• Disadvantages:
  – Can lead to excess oscillation or instability
The closed-loop control TF

Using block diagram algebra, you can solve for output

\[ c = \frac{G_c G_p}{1 + G_c G_p H} \cdot r + \frac{G_p}{1 + G_c G_p H} \cdot u_d \]

More opportunities to design how the system responds to the reference input \( r \) as well as to disturbances \( u_d \)
Why derive a closed-loop transfer function (TF)?

You can prove some of the properties we discussed.

1. First, show how the closed loop TF is derived
2. Use the TF to show effect on a closed loop controller output if there is a variation in the system parameters or a variation in the disturbance

These simple relations show that a controller relies on proper tuning of the controller. The mathematical models can be used for this purpose.
Basic control actions used in $G_c(s)$

- Proportional (P) control
- Integral (I) control
- Derivative (D) control
- Combination: PI, PD, PID

Most industrial controllers (well over 90 to 95%) you will run across will be of a PID type.
Example: proportional control

\[ G_c(s) = K_p = \text{constant} \]

\[ \frac{X_c}{X_R} = \frac{G}{1 + GH} = \frac{K_p G_p \cdot 1}{1 + K_p G_p \cdot 1} = \frac{K_p}{ms^2 + bs + k + K_p} \]

Closed-loop

\[ u = K_p \cdot e \]

\[ U(s) = K_p E(s) \]

\[ \frac{X}{F} = \frac{1}{ms^2 + bs + k} \]
Forming I, D, and PID

**Integral control:**  
\[ u = \frac{K_I}{T_L} \int e \, dt \Rightarrow U(s) = \frac{K_I}{T_L s} E(s) \]  
Integral control reduces or eliminates steady-state error, but has reduced stability.

or,  
\[ u = K_I \int e \, dt \Rightarrow U(s) = \frac{K_I}{s} E(s) \]

**Derivative control:**  
\[ u = K_D T_D \frac{de}{dt} \Rightarrow U(s) = K_D T_D s E(s) \]  
Derivative control yields an increase in effective damping, improving stability.

**PID control:**  
\[ U(s) = K \left( 1 + \frac{1}{T_L s} + T_D s \right) E(s) \]

or,  
\[ U(s) = \left( K_p + \frac{K_I}{s} + K_D s \right) E(s) \]  
The basic idea is to tune the controller by choosing the gains so specifications are met.
Feedforward Control

- One of the key attributes feedback control adds to a system is the ability to diminish the influence of disturbances.
- If you know or measure the disturbances before they influence a system, it might be possible to nullify the effect on system performance.
- One way of doing this is to use feedforward control.
Feedback with Feedforward

\[ R(s) \rightarrow E(s) \rightarrow G_c(s) \rightarrow U(s) \rightarrow G_p(s) \rightarrow C(s) \]

Feedforward

Disturbances

\[ D(s) \]

\[ H(s) \]

\[ G_{FF}(s) \]

\[ Y(s) \]

Control
Stability

• The stability of a system refers to its ability or tendency to seek a condition of static equilibrium after it has been disturbed.

• If given a small perturbation from the equilibrium, it is stable if it returns.