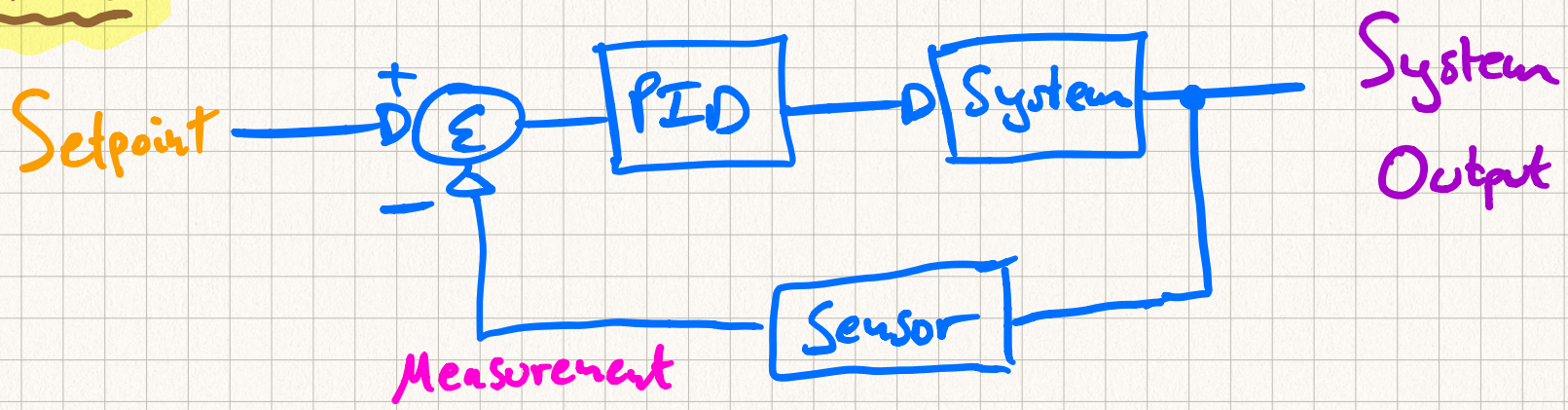
PID Controller Implementation in Software

- Overview.
- Converting from continuous to discrete time.
- Practical considerations.
- PID code in C (for embedded systems).
- Example application.

Overview



→ Want to make system output track desired setpoint via feedback!

→ PID controller takes <u>two</u> inputs and produces a control signal.

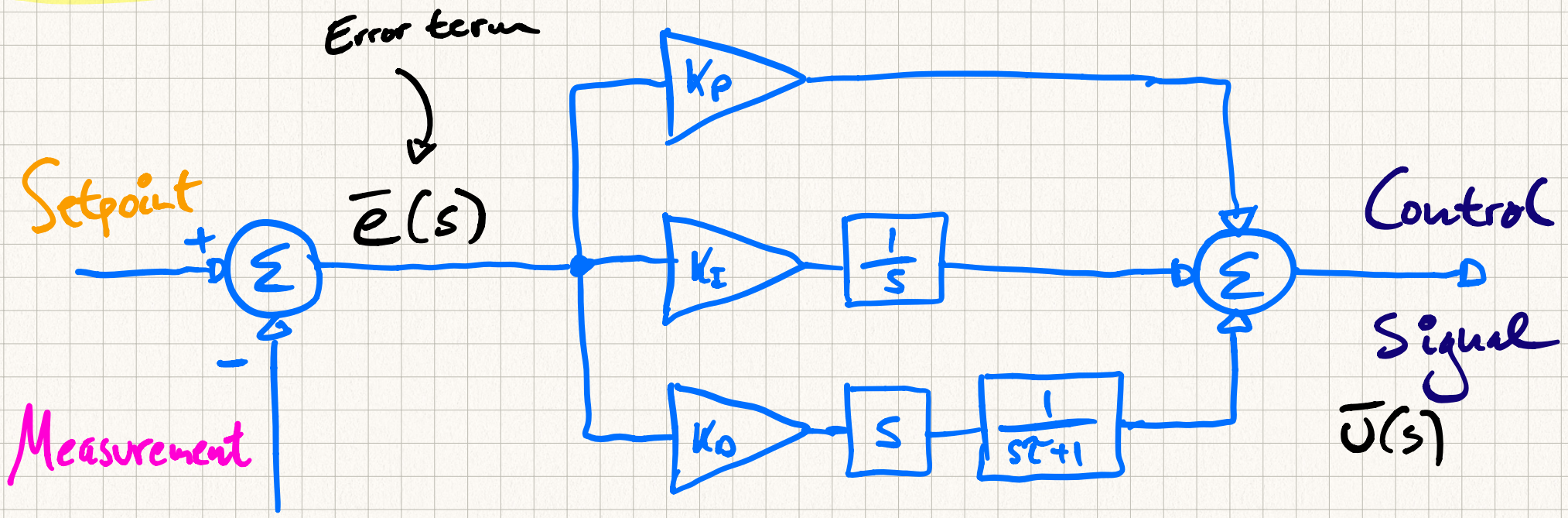
setpoint

measurement

→ System usually in continuous time, PID controller usually implemented digitally.

⇒ How can we write the controller in code?

PID in Continuous Domain



$$G(s) = \frac{\bar{u}(s)}{\bar{e}(s)} = \underbrace{K_P}_{\text{Proportional}} + \underbrace{K_I \cdot \frac{1}{s}}_{\text{Integral}} + \underbrace{K_D \cdot \frac{s}{s\tau+1}}_{\text{(Filtered) Derivative}}$$

Continuous to Discrete

Can implement this in code!

→ I.e. s-Domain to z-Domain to difference equation!

→ Use Tustin transform (best frequency domain match)

① Substitute $s \rightarrow \frac{2}{T}\frac{z-1}{z+1}$

② Recall: $\bar{Y}(z) = \bar{X}(z) \cdot z^{-1} \Rightarrow y[n] = x[n-1]$

($T \hat{=}$ sampling time of discrete controller in seconds)

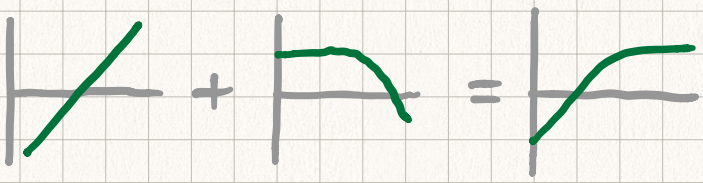
After a lot of substituting and rearranging...

$$
\left[\begin{aligned}
p[n] &= K_p \cdot e[n] \\
i[n] &= \frac{K_I T}{2}\left(e[n] + e[n-1]\right) + i[n-1] \\
d[n] &= \frac{2K_D}{2\tau + T}\left(e[n] - e[n-1]\right) + \frac{2\tau - T}{2\tau + T}\, d[n-1]
\end{aligned}\right]
\begin{array}{l} P \\ I \\ D \end{array}
$$

$$\Rightarrow u[n] = p[n] + i[n] + d[n]$$

Controller output

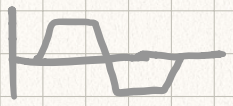
Practical Considerations



→ Derivative amplifies HF noise. Derivative filter!

→ Derivative "kick" during setpoint change. Derivative-on-measurement!

→ Integrator can saturate output. Integrator anti-windup!



→ Limits on system input amplitude. Clamp controller output!

→ Choosing a sample time T. $T_{controller} < \frac{T_{BW,\,system}}{10}$

Code Structure

→ Header-file "library". (#include "pid.h")

→ PID controller struct. (contains gains, storage variables, ...)

→ Initialisation function. (set gains, sample time, ...)

→ Update function. (provide setpoint and measurement, returns controller output)