PID Control: A Tutorial for Physicists

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Overview

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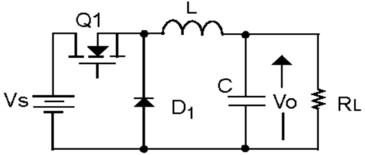
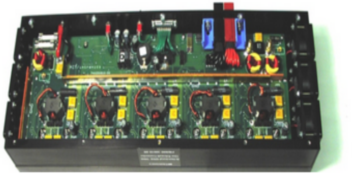
- And obviously in Physics as well ! ☺

Motivation: Electrical Engineering

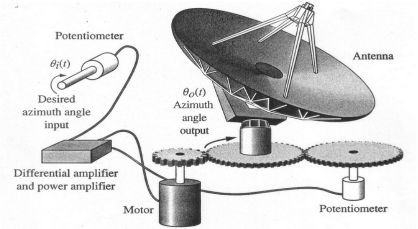
- Designing of sophisticated switching power regulators which are almost in every electrical device.
- Rely heavily on feedback and can be unstable if designed incorrectly.

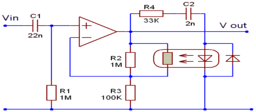




Motivation: Communications Engineering

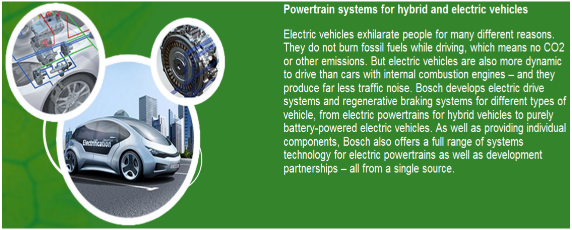
- Designing of antenna azimuth position control for satellite tracking and automatic gain controllers (AGC).
- Obviously feedback control applications.





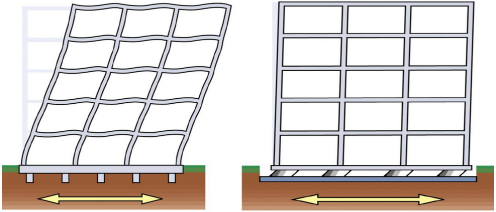
Motivation: Mechanical Engineering

- Designing of isolation systems for vibration and damping control in a structure.
- Control applications include absorbing motor vibrations using powertrain mounts to reduce fuel consumption in hybrid and electric vehicles.



Motivation: Civil Engineering

- Designing structures located in environments where earthquakes or large wind forces are common.
- May require active or semi-active control systems.

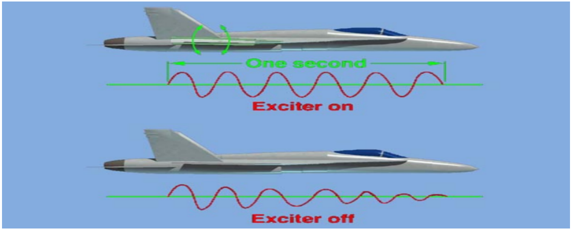


Motivation: Industrial Engineering

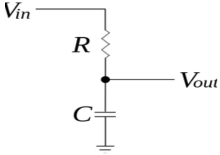
- Designing robotic assembly lines for cooperative control of manipulators.
- Or tunning of PID loops for individual robotic arms.

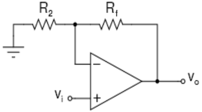
Motivation: Aerospace Engineering

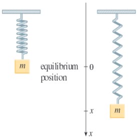
- Solving the air-craft flutter problem for smooth flights.
- Various control strategies can be applied to tackle it.

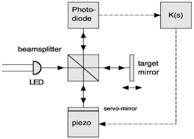


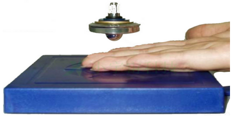
Motivation: And in Physics as well ☺, for the control of

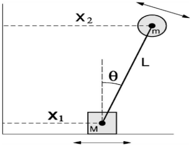












And many other systems which are the core of physics !

Control System

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- The system to be controlled is also called plant.

Control System

- Sometimes plant is decomposed into actuator and process for mathematical analysis.

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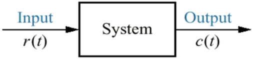
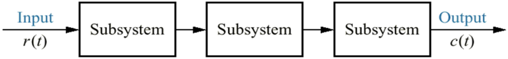
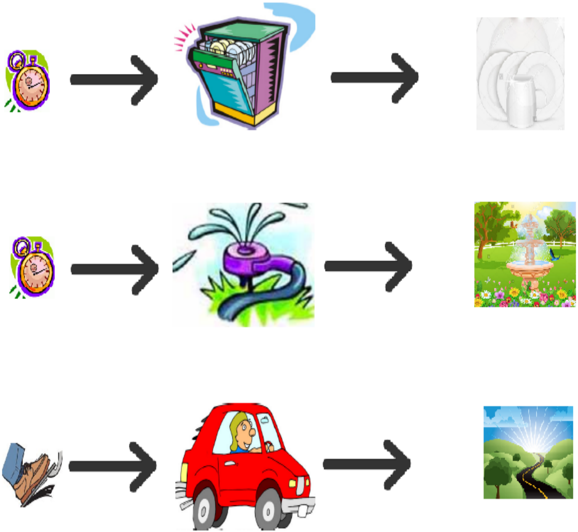




Control System : Open Loop Control Systems



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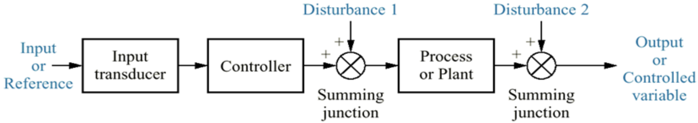
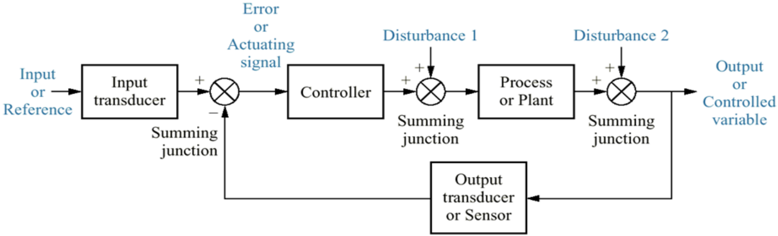
- Feedback control systems are very robust against internal or external disturbances.

Feedback Control Systems





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- So both have pros and cons. But we prefer feedback control systems for sophisticated applications.

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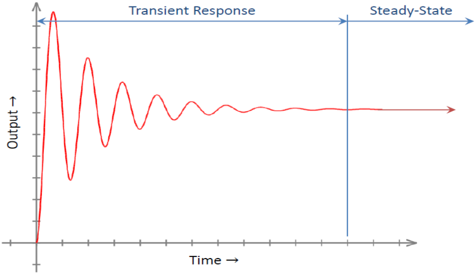
- Total response of the system is the sum of both of these.



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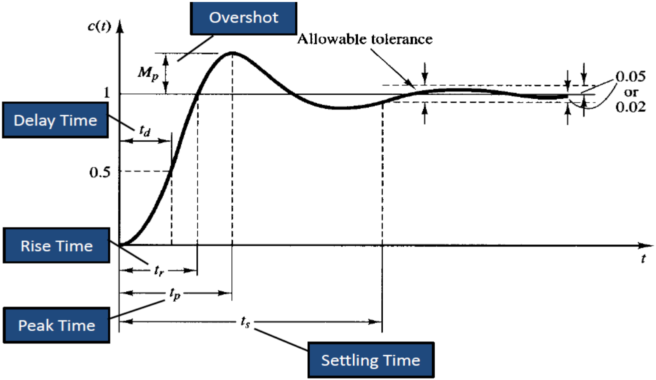
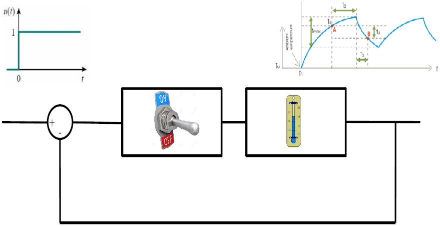
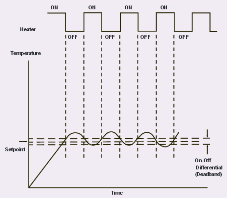


ON-OFF Controller

1. Simplest type of feedback controller is an ON-OFF controller.
2. Temperature control of a chamber using a thermostat is a good example.
3. An on-off controller will switch the output only when the output crosses the setpoint.





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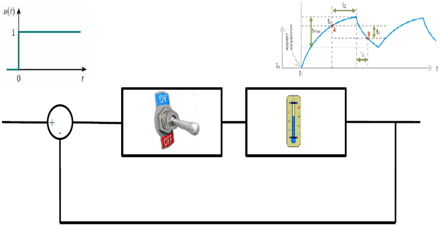
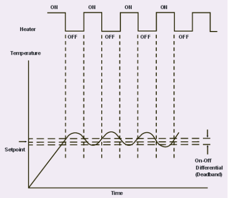
4. A common problem with such type of controllers is oscillations in output.





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- PID is an acronym for Proportional, Integral and Derivative.
- Mathematically, it can be expressed as:

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

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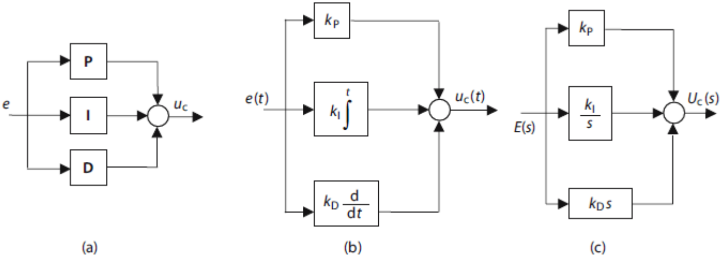
- It is simply the sum of three parallel controllers operating on error signal to generate a combined control output.

PID Controller



Key	Controller input (system error)	e	PID control signal	u_c	
Symbolic forms	e, u_c	Time domain forms	$e(t)$, $u_c(t)$	Laplace domain forms	$E(s)$, $U_c(s)$
Proportional gain	k_P	Integral gain	k_I	Derivative gain	k_D

PID controller representations.

PID Controller

Proportional control

It is used when the controller action is to be proportional to the size of the process error signal.

Integral control

It is used when it is required that the controller correct for any steady offset from a constant reference signal value. Integral control overcomes the shortcoming of proportional control by eliminating offset without the use of excessively large controller gain.

Derivative control

If a controller can use the rate of change of an error signal as an input, then this introduces an element of prediction into the control action. Derivative control uses the rate of change of an error signal.

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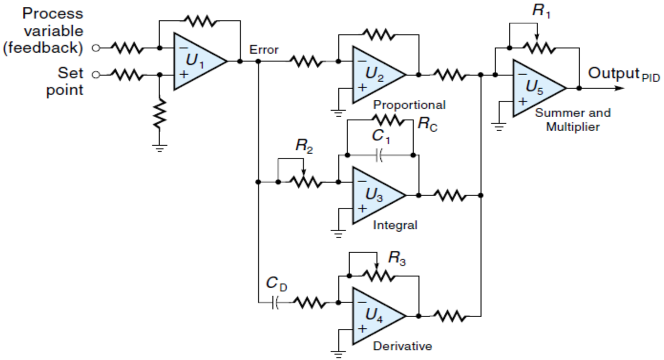
- PID controllers can be implemented with both analog and digital components.

PID Controller

An analog PID controller.



PID Controller

- Algorithm for digital implementation on a micro-controller:

```
previous_error = 0
integral = 0
start:
  error = setpoint - measured_value
  integral = integral + error*dt
  derivative = (error - previous_error)/dt
  output = Kp*error + Ki*integral + Kd*derivative
  previous_error = error
  wait(dt)
  goto start
```

PID Controller

- The selection of the PID gains (K_p, K_i and K_d), i.e., the tuning of the PID controllers, is obviously the crucial issue in the overall controller design.
- Simplest way of PID tuning is through hit and trial using following table:

Effects of *increasing* a parameter independently

Parameter	Rise time	Overshoot	Settling time	Steady-state error	Stability
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor change	Decrease	Decrease	No effect in theory	Improve if K_d small

PID Controller

- Sophisticated methods do exist for PID tuning like Ziegler-Nichols (Z-N) method:

I
- Set the true plant to proportional control.
- Use very small gain

II
- Increase the gain until the loop starts oscillating
- (e.g. oscillations should be checked at controller output)

III
- Record the controller critical gain $K_p = K_c$
- Also record the oscillation period P_c

IV
- Adjust the controller parameters according to the following table:

$$C(s) = K_P\left(1 + \frac{1}{T_r s} + T_d s\right)$$

	K_p	T_r	T_d
P	$0.5\ K_c$		
PI	$0.45\ K_c$	$P_c/1.2$	
PID	$0.6\ K_c$	$0.5\ P_c$	$P_c/8$

Conclusion

- The PID control algorithm is a robust and simple algorithm that is widely used in the industry.
- The algorithm has sufficient flexibility to yield excellent results in a wide variety of applications and has been one of the main reasons for the continued use over the years.
- PID controller can be implement with NI LabVIEW and NI plug-in data acquisition devices with higher accuracy and better performance.

References

- *Norman S. Nise, "Control Systems Engineering", 2007*
- *Michael A. Johnson & Mohammad H. Moradi, "PID Control", 2005*.
- *Graham Clifford Goodwin, Stefan F. Graebe, and Mario E. Salgado, "Control System Design" Prentice Hall, 2001*.
- Lecture notes of my Professor (Dr Kashif Saeed, UET, Lahore) ☺

Thank You & Questions If Any?