Introduction to Selected Research Topics in Mechanical Engineering II

Automatic Control Theory & Applications

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Topics

- What is automatic control?
- Open-loop and closed-loop control
- On-off control
- PID control
- Control applications

Control Theory

The aim of a control system is to maintain (regulate) the system output (system response) at a predetermined (desired) level by using the control input.

A control system consists of an input (objective), the control element and its output (result).

Figure The basic components of a control system.

Disturbance:

A disturbance is a signal that adversely effect the value of the output of a system

There are two main types of control systems:

1) Open-loop systems

2) Closed-loop systems

Open-loop systems

The open-loop system is also called the non-feedback system.

A simple example is illustrated by the speed control of an automobile as shown in Figure. In this open-loop system, there is no way to ensure the actual speed is close to the desired speed automatically. The actual speed might be way off the desired speed because of the wind speed and/or road conditions, such as up hill or down hill etc.

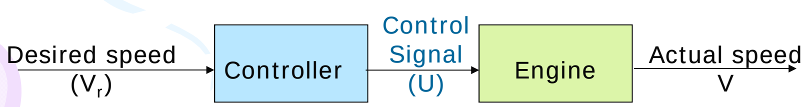


Figure Basic open-loop system

Closed-loop systems

The closed-loop system is also called the feedback system. A simple closed-loop system is shown in Figure.

It has a mechanism to ensure the actual speed is close to the desired speed automatically.

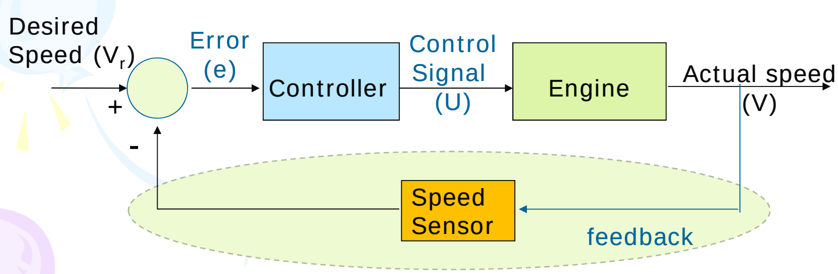


Figure Basic closed-loop system

On-off control

On-off control is may be the most simple controller structure.

It has only two positions : "**On**" and "**off**"

This is why it is known as **two position controller**.

The output of the controller is of the form:

$$u(t) = \begin{cases} u_1 \ ; \ e(t) > 0 \\ u_2 \ ; \ e(t) < 0 \end{cases}$$

Here u_2 is generally $u_2 = 0$ or $u_2 = -u_1$

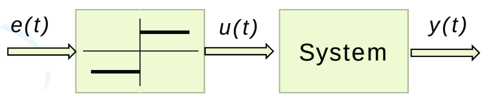


Figure On-off controller

A thermostat is a simple example:

When the temperature goes below a set point (desired value),

then the heater is switched on.

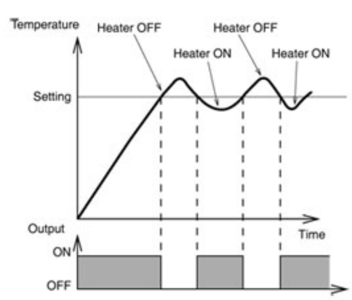


Figure Temperature and control signal variation

PID control

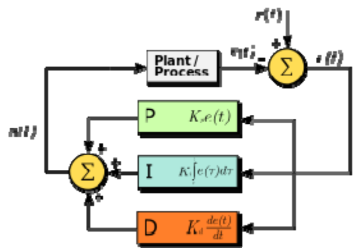
Proportional+Integral+Derivative (PID) signal is calculated as below where e(t)=(ref value - actual value) is the error signal.

$$u(t) = \underbrace{K_p e(t)}_{\text{Proportional term}} + \underbrace{K_p \frac{1}{T_i}\int_0^t e(t)dt}_{\text{Integral term}} + \underbrace{K_p T_d \frac{de(t)}{dt}}_{\text{Derivative term}}$$

K_p : Proportional gain

T_i : Integral time

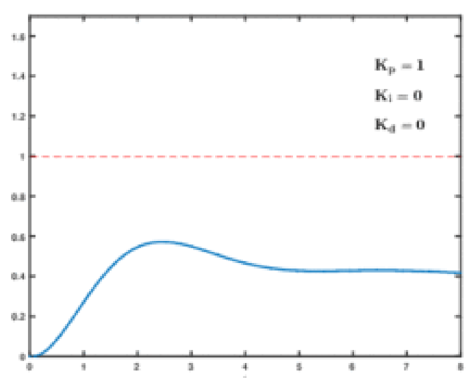
T_d : Derivative time



The **proportional term** in the controller generally helps in establishing system stability and improving the transient response

The **derivative term** is often used when it is necessary to improve the closed loop response speed even further.

The most important term in the controller is the **integrator term** that improves steady state setpoint tracking.



Ziegler-Nichols method for PID tuning

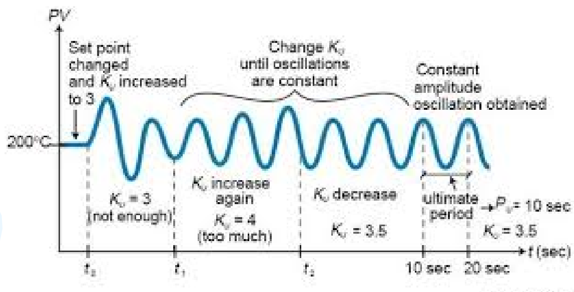
Using only proportional feedback control:

1. Reduce the integrator and derivative gains to 0.

2. Increase K_p from 0 to some critical value $K_p=K_{cr}$ at which sustained oscillations occur. If it does not occur then another method has to be applied.

3. Note the value K_{cr} and the corresponding period of sustained oscillation, P_{cr}

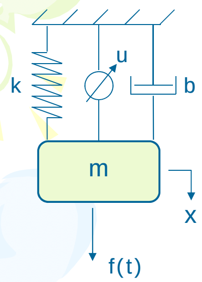
The controller gains are now specified as follows:



Controller parameters according to Ziegler-Nichols method

PID Type	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{P_{cr}}{1.2}$	0
PID	$0.6K_{cr}$	$\frac{P_{cr}}{2}$	$\frac{P_{cr}}{8}$

Example



$$m\ddot{x} + b\dot{x} + kx = f(t) + u$$

Equation of motion

$$f(t) = \begin{cases} F\sin(t) & 0 \le t \le 1 \\ 0 & t > 1 \end{cases}$$

$$x(0) = 0 \;\; ; \;\; \dot{x}(0) = 0$$

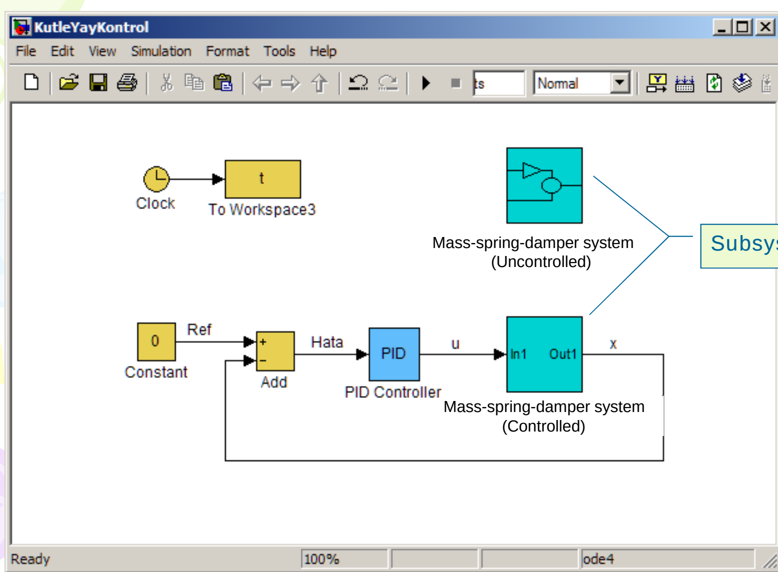
Initial conditions

$$m\ddot{x} + b\dot{x} + kx = f(t) + u \quad \Rightarrow \quad \ddot{x} = \frac{1}{m}\left(f(t) - b\dot{x} - kx + u\right)$$

PID controller will be used

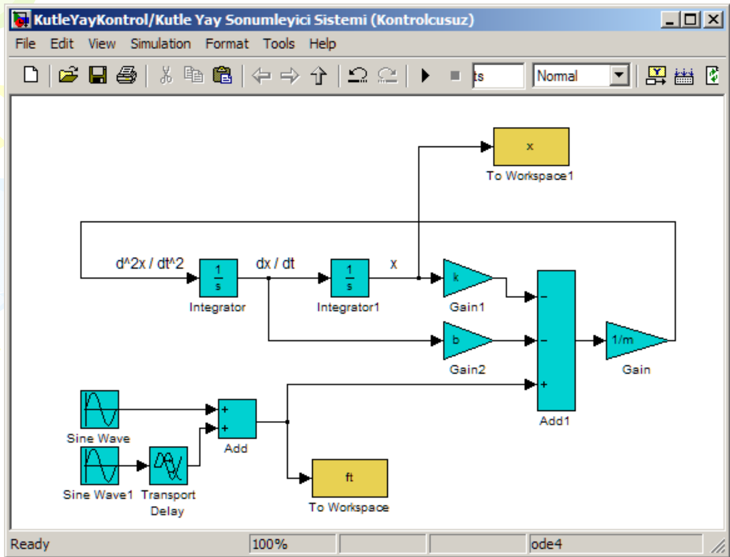
Block diagram will be constructed using this equation

Mass-spring-damper system



Subsystem

Without controller



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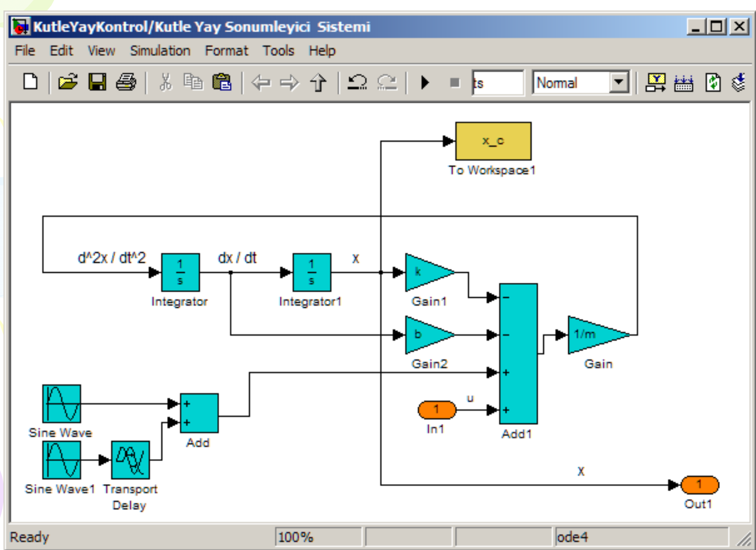
With PID control



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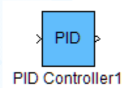
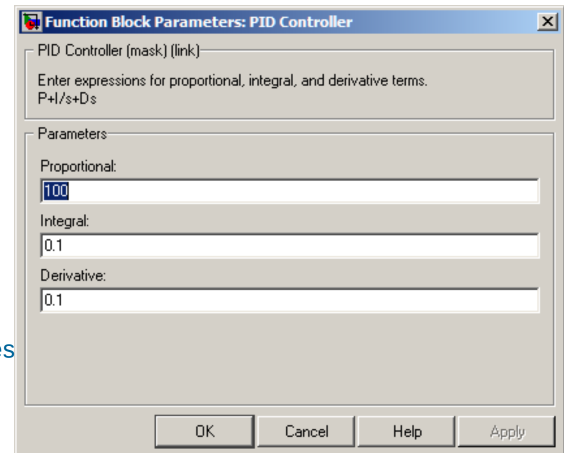
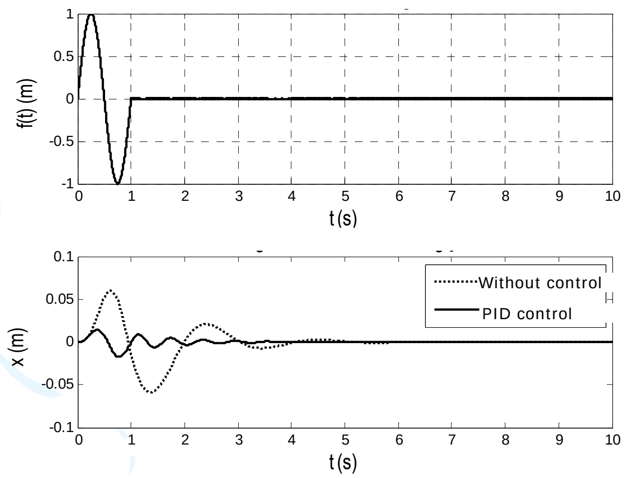




Matlab
⇒Blocksets & toolboxes
⇒Simulink extras
⇒Additional linear


```
% Simulation parameters
ti=0;
ts=10;
dt=0.001;
% model parameters
m=1;
k=10;
b=2;
F=1;

figure(1);
subplot(2,1,1);
plot(t,ft,'k','linewidth',2);
xlabel('t (s)');ylabel('f(t) (m)');grid on;
subplot(2,1,2);
plot(t,x,':k','linewidth',2);hold on;plot(t,x_c,'k','linewidth',2);
xlabel('t (s)');ylabel('x (m)');
legend('Without control','PID control');
```



Control Applications

It is possible to state that Watt's speed governor (fly-ball governor) is the first industrial automatic control application.

It is designed to regulate the speed of an engine.

The amount of fluid admitted to the engine is adjusted according to the difference between actual and desired engine speeds.

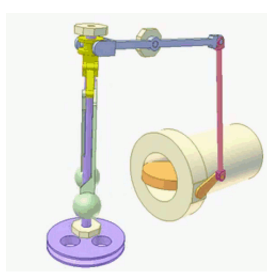


Figure Watt governor (fly-ball governor)

In recent years, control systems have gained an increasing importance in the development and advancement of the modern civilization and technology.

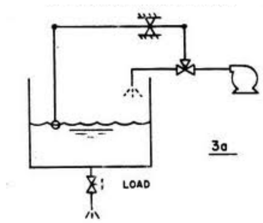


Figure Water level control

http://www.atp.rub.de/DynLAB/dynlabmodules/Examples/WhatIsControl/WaterLevel5.html

Robot arms are widely used in manufacturing systems

Autopilot systems

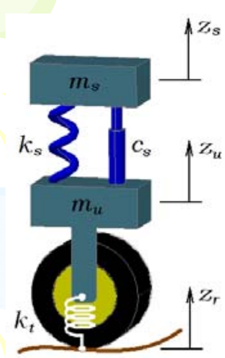
Mobile robots are preferred for space tasks and for hazardous environments

Manually operated robot arms are used for surgery

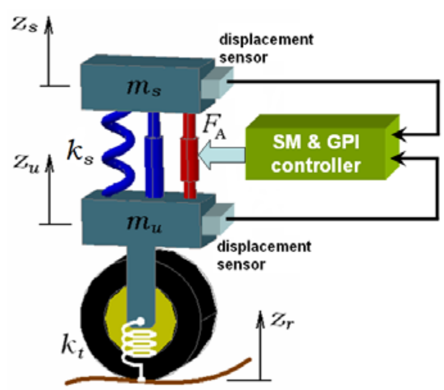
The important functions of vehicle suspensions:

- To support vehicle.
- To minimize the forces transmitted to passengers.
- Consequently to improve the ride comfort.

Figure Active suspension systems provide high ride quality or good road holding



Passive (conventional) suspension



Active suspension

Bose active suspension:
https://www.youtube.com/watch?v=eSi6J-QK1lw