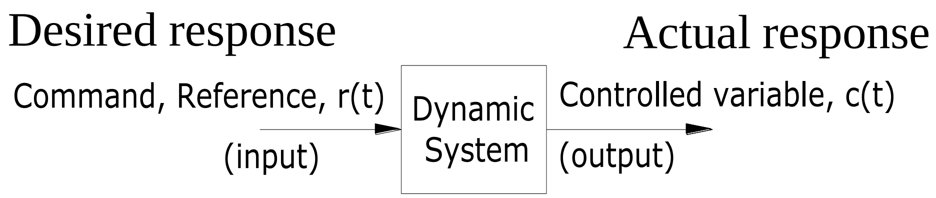
CONTROL SYSYEMS

1.1 What is a Control System?

➢ Our environment is surrounded by systems (Mechanical, Electrical, Thermal, Fluid, Biological, Economic, and/or combinations) which are needed to exhibit some desired response.

➢ A control system is an interconnection of components forming a system configuration that will provide the desired system response.



Basic components of a control system

System – An interconnection of elements and devices for a desired purpose.

Control System – An interconnection of components forming a system configuration that will provide a desired response.

1.1 What is a Control System? (continued)

Systems can be controlled mainly in two ways

Manual Control:

1. Human controlling the speed of an automobile by regulating the gas supply to the engine by using the gas pedal.
2. Assembling machine parts by hand done by workers
3. A soldier using a bazooka to hit a target.
4. Opening a valve by hand to adjust the desired water level.
5. Opening or closing of a window for regulating air temperature or air quality,

* Try to figure out more examples yourselves !!!

Automatic Control:

1. Cruise control systems

2. Robotic assembly lines

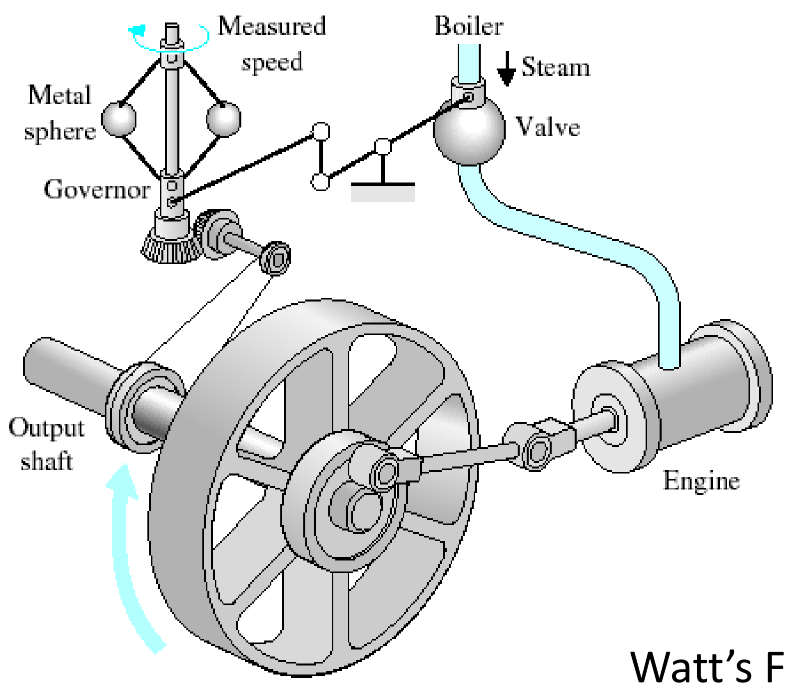
3. Missile guidance systems

4. Automatic water level control systems

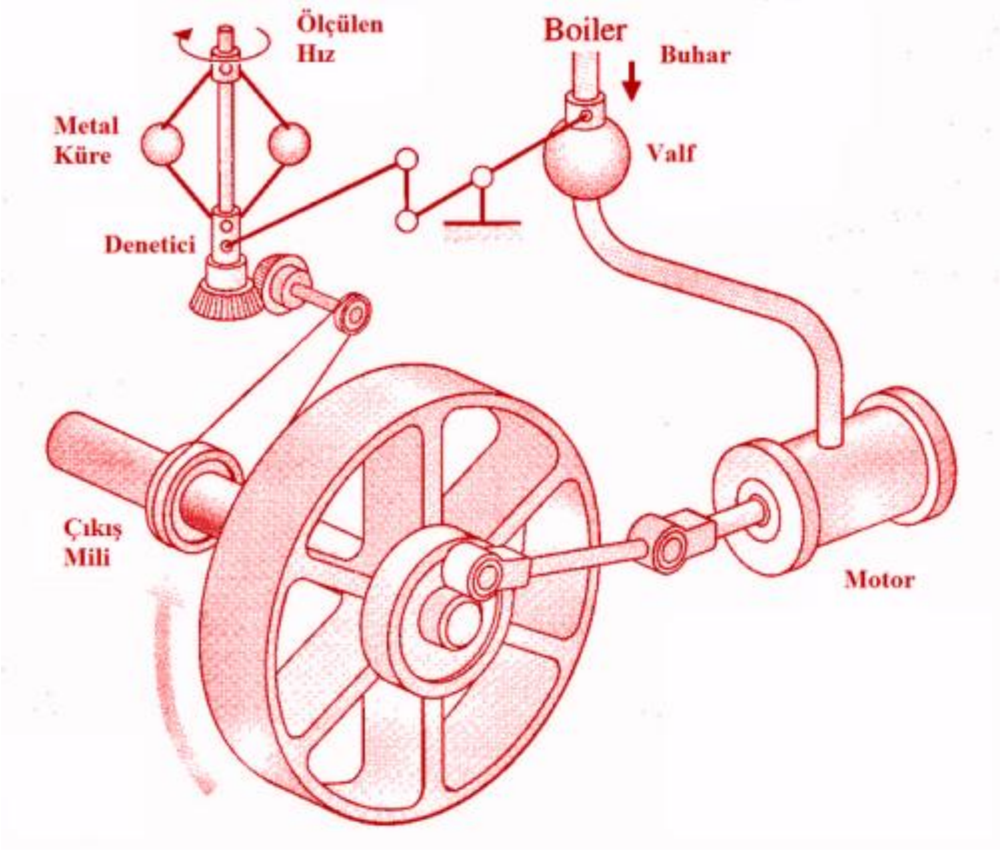
5. Residential heating and air-conditioning systems controlled by a thermostat

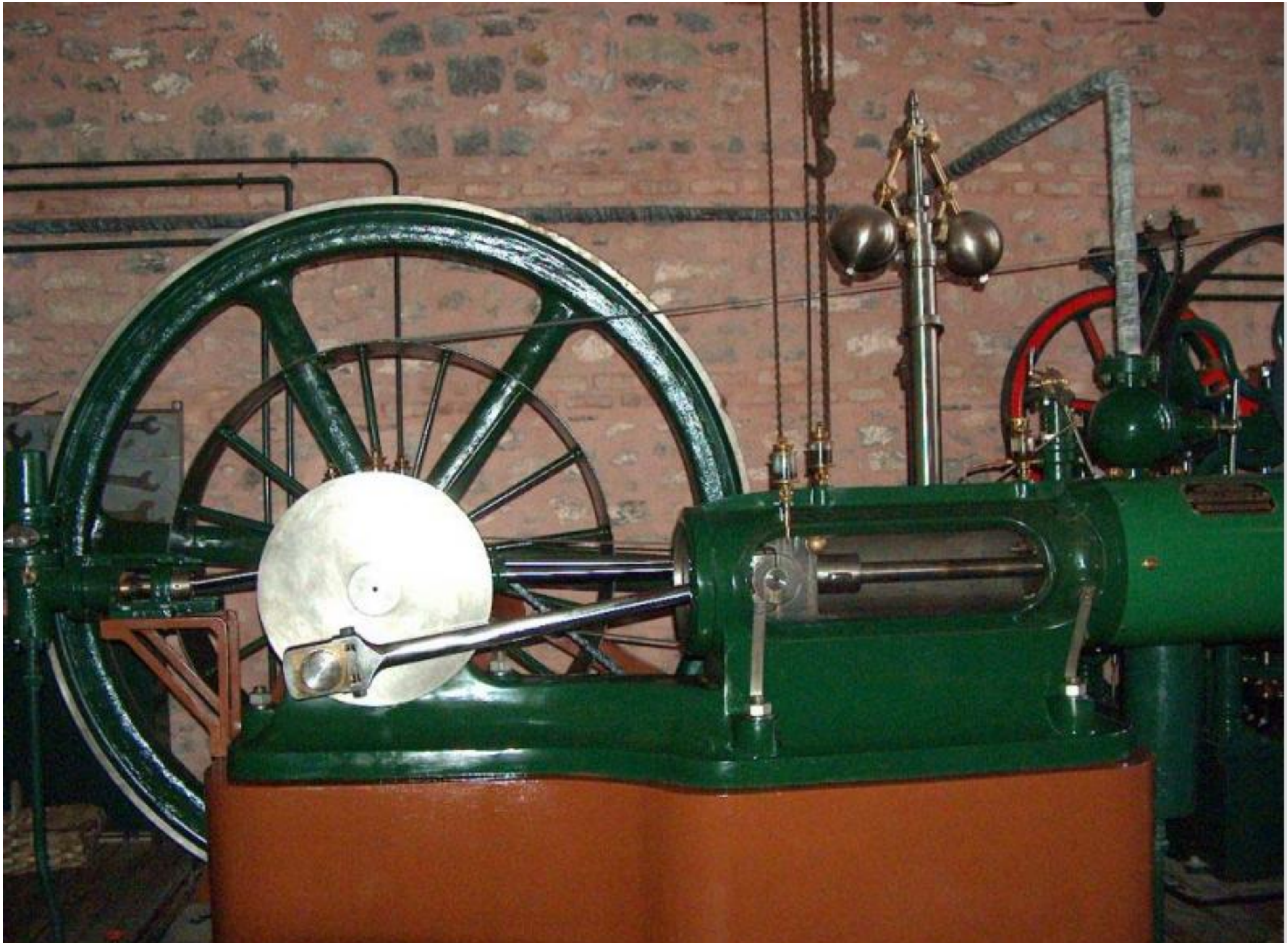
History

Greece (BC) – Float regulator mechanism
Holland (16th Century)– Temperature regulator



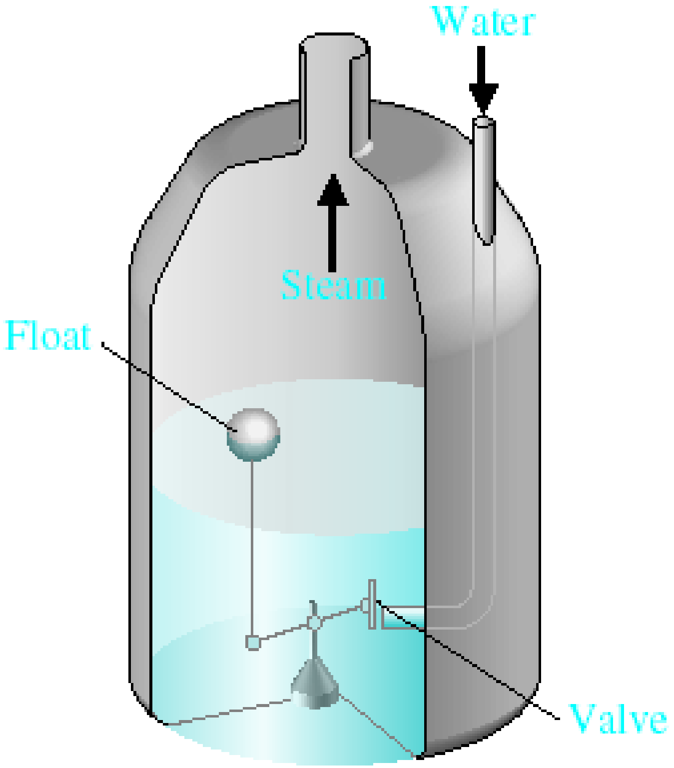
Watt's Flyball Governor
(18th century)


Ölçülen
Hız
Boiler
Buhar
Metal
Küre
Valf
Denetici
Çıkış
Mili
Motor

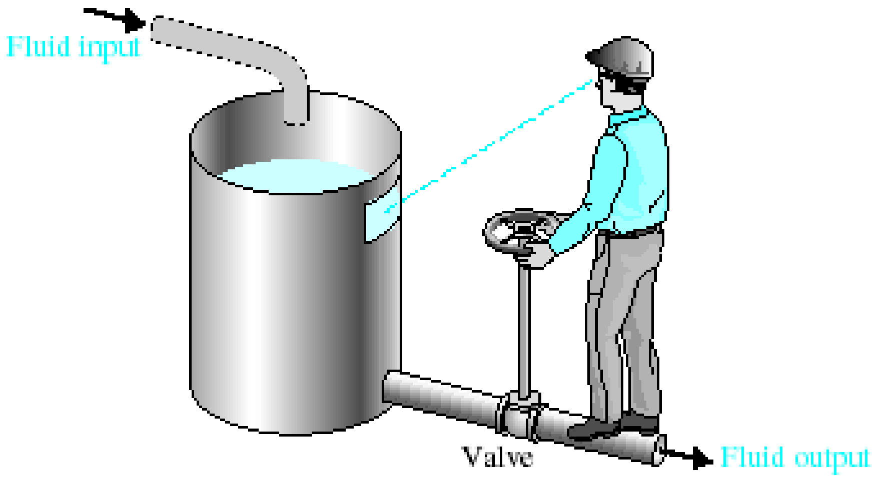


History

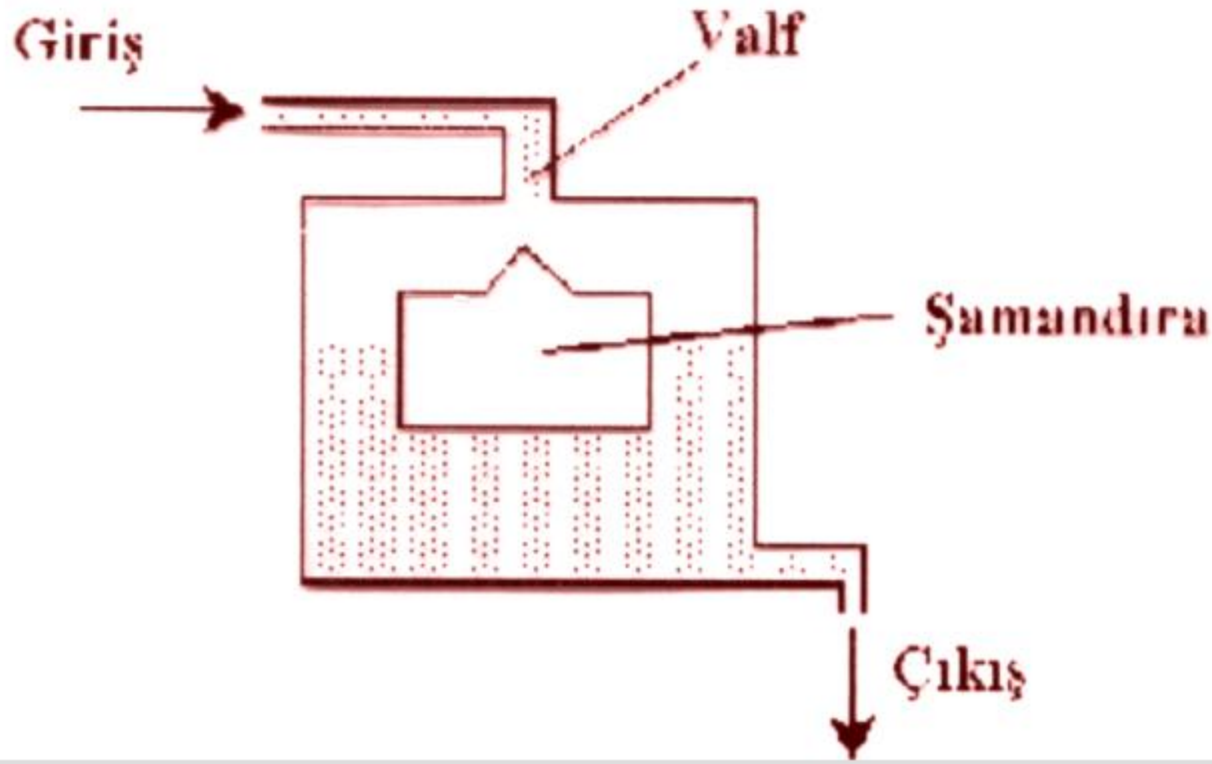
Water-level float regulator



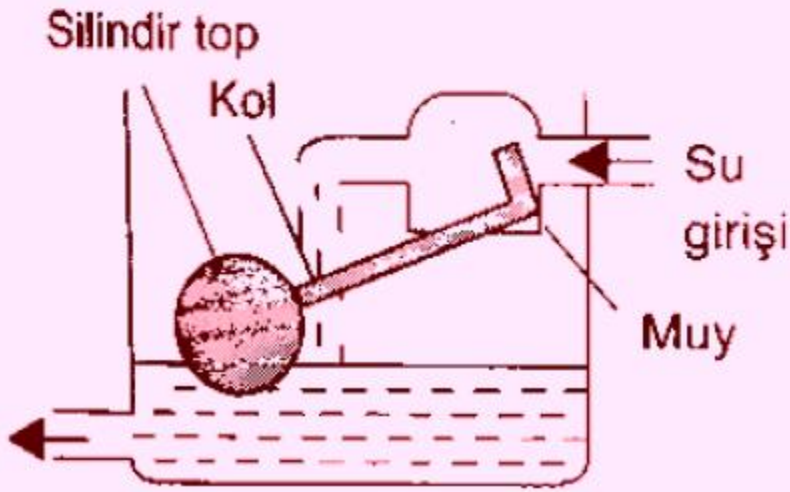
Examples of Modern Control Systems



A manual control system for regulating the level of fluid in a tank by adjusting the output valve. The operator views the level of fluid through a port in the side of the tank.

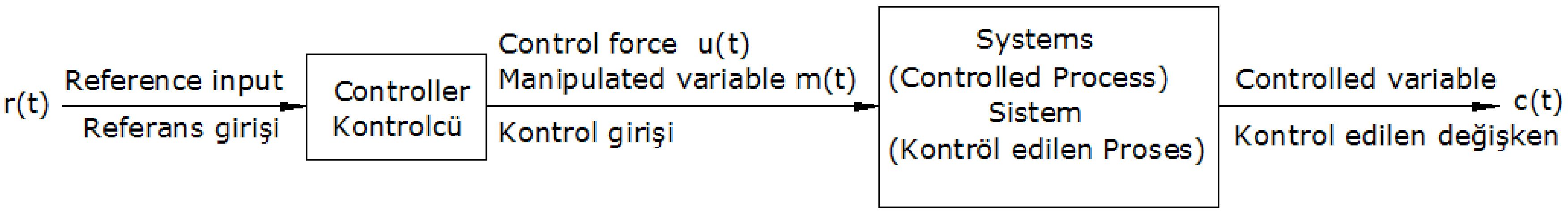


Giriş
Valf
Şamandıra
Çıkış



Şek. 1.10 Su seviyesinin otomatik kontrolu

A. Open-loop control systems (cont'd):



Elements of an open - loop control system.

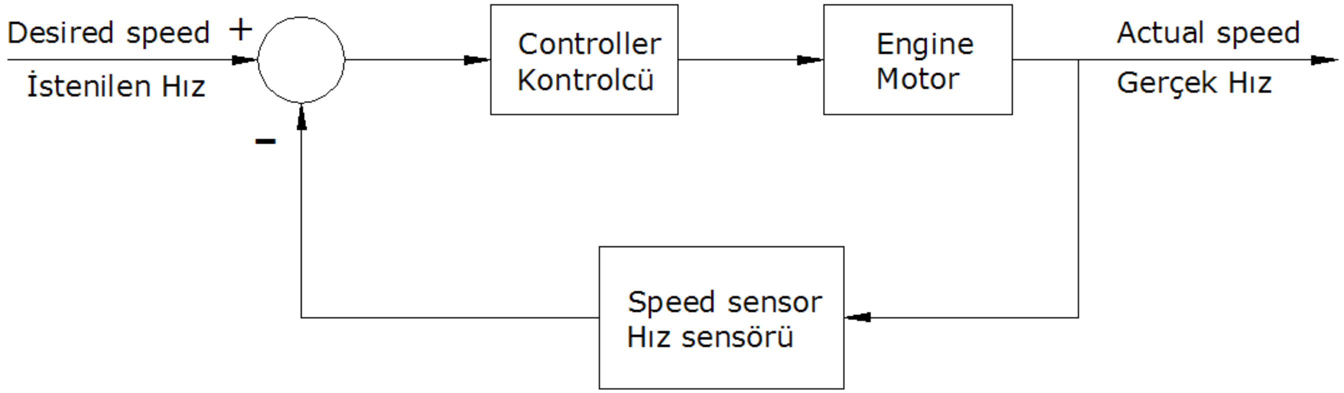
Open-Loop Control Systems utilize a controller or control actuator to obtain the desired response.

Examples:

- A traffic control system is a good example of an open loop system. The signals change according to a preset time and are not affected by the density of traffic on any road.

- A washing machine is another example of an open loop control system. The quality of wash is not measured; every cycle like wash, rinse and dry cycle goes according to a preset timing.

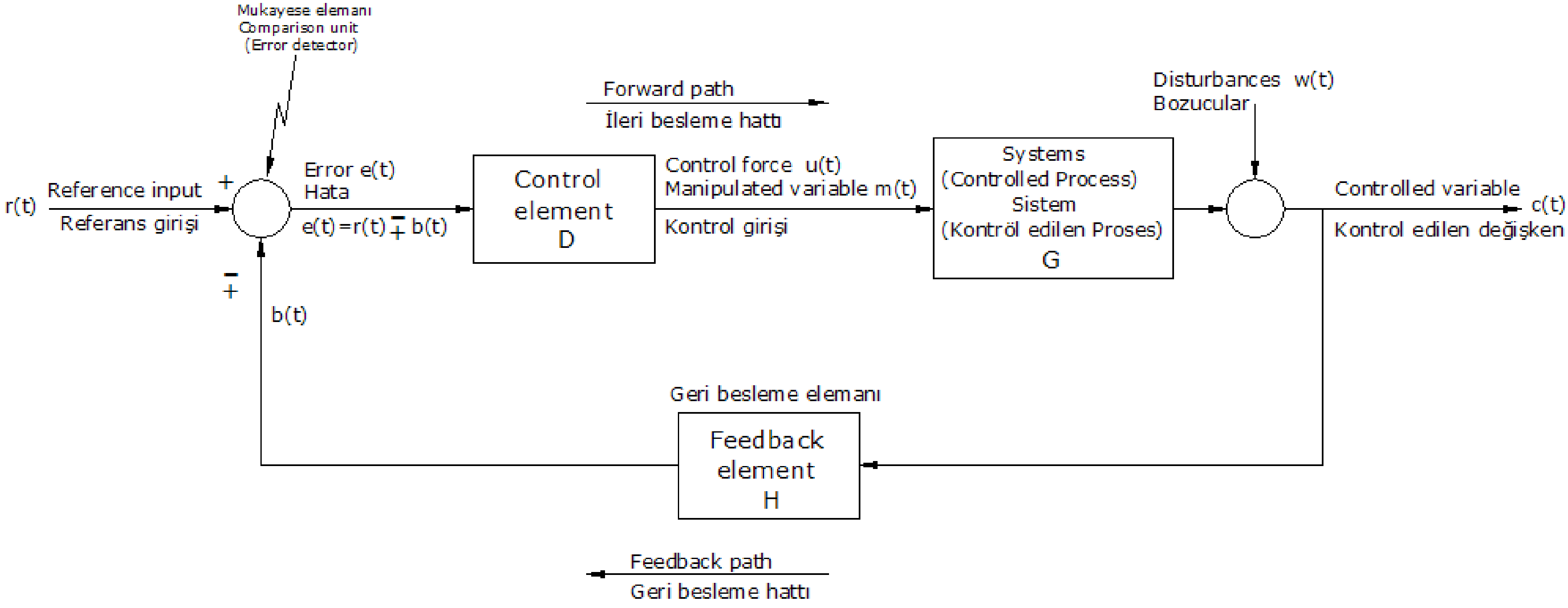
Closed-loop (Feedback) control systems:



Basic closed-loop control system

Closed-Loop Control Systems utilizes feedback to compare the actual output to the desired output response.

B. Closed-loop (Feedback) control systems (cont'd):



Elements of a closed-loop control system.

Closed loop systems

- are more complex,
- Use more number of elements to build and are costly.
- are insensitive to external disturbances and variations in parameters.
- maintenance is more difficult than open loop systems.

Examples of Control Systems

Feedback control systems are used extensively in industrial applications. Examples:

Speed Control System:

- The first significant work in automatic control was James Watt's centrifugal governor (Watt's flyball) for the speed control of a steam engine in the eighteenth century.

- In Watt's flyball governor, the aim is to make steam engine run at a constant speed (Fig. 1.6).

Working Principle: The amount of steam admitted to the turbine is adjusted according to the difference between the desired and the actual engine speeds.

The speed governor is adjusted such that, at the desired speed, no pressurized oil will flow into either side of the power cylinder. If the actual speed drops below the desired value due to disturbance or loading, then the decrease in the centrifugal force of the speed governor causes the piston of the pilot cylinder go downwards resulting the control valve to move upwards, supplying more steam. Then, the speed of the engine increases causing the pilot cylinder's piston move upwards until the desired value is reached. When the desired turbine speed is obtained, the pilot cylinder's piston closes the ports of the power cylinder. On the other hand, if the speed of the engine increases above the desired value, then the increase in the centrifugal force of the governor causes the control valve to move downwards. This decreases the supply of steam, and the speed of the engine decreases until the desired value is reached.

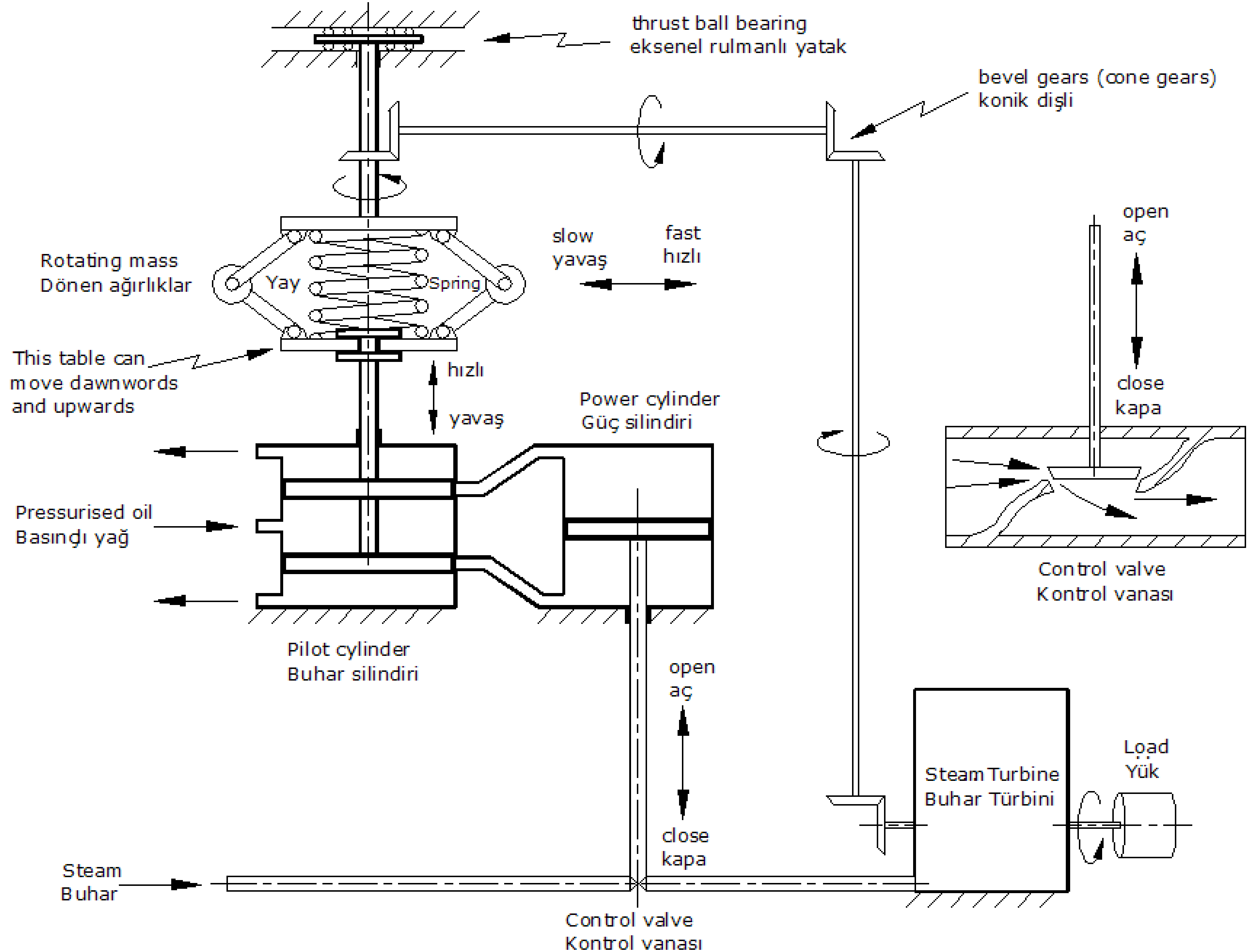
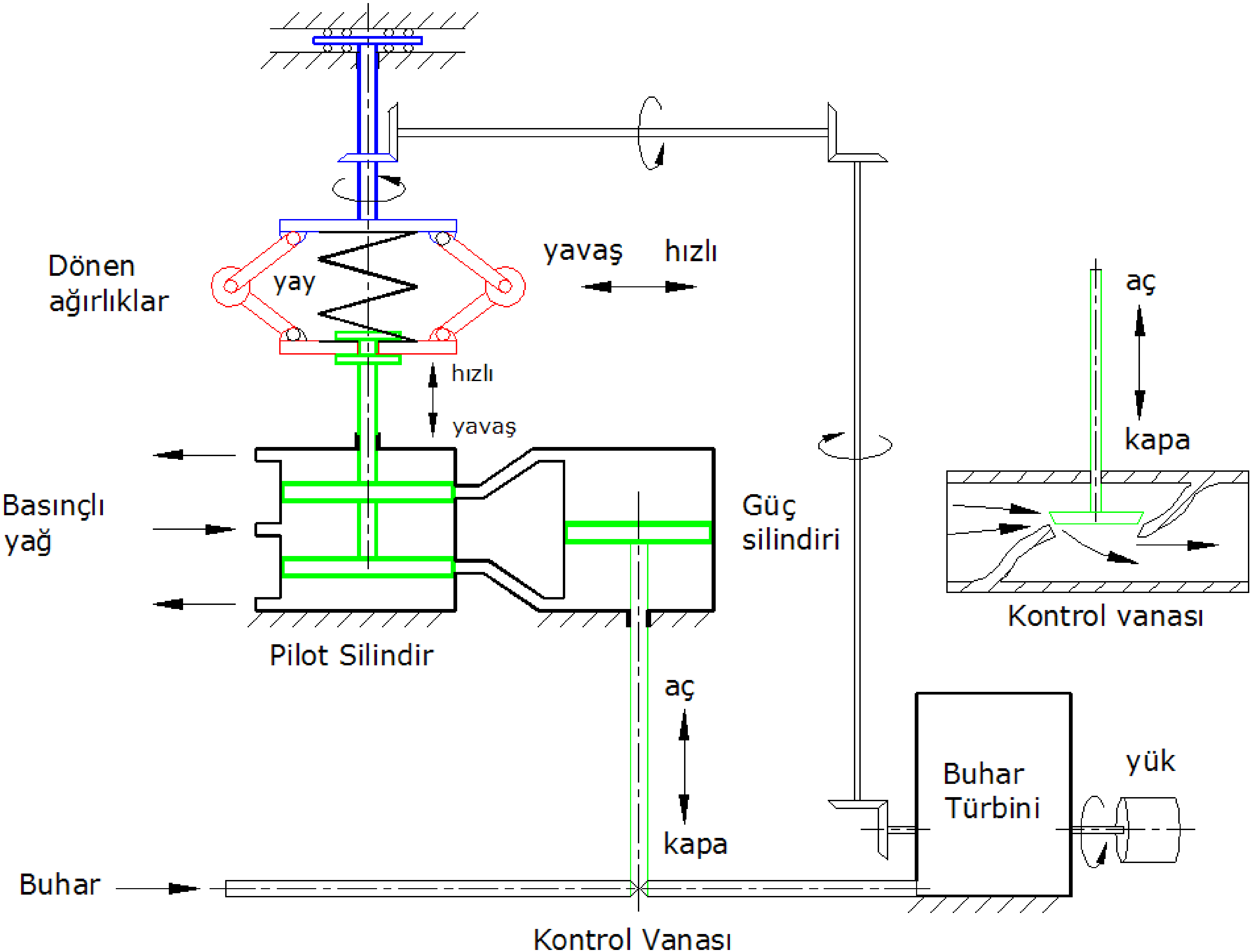
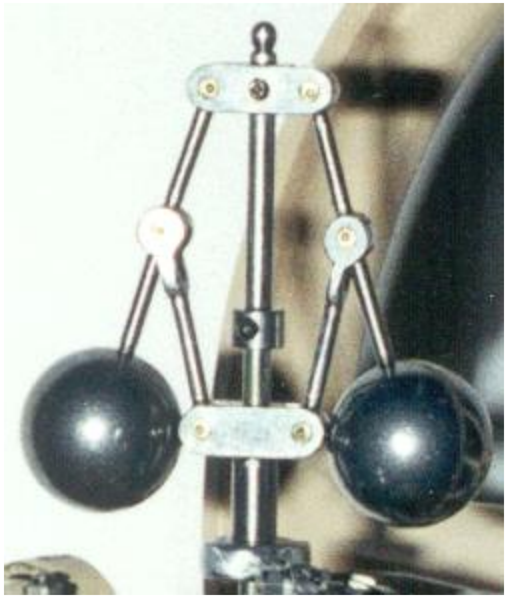
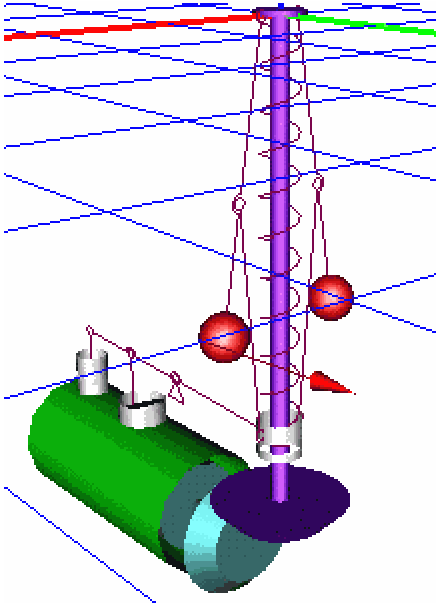


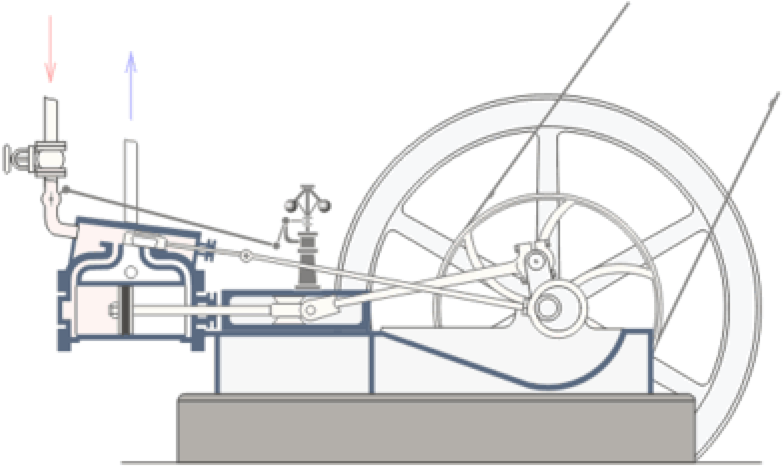
Fig. 1.6. Watt’s Flyball Governor



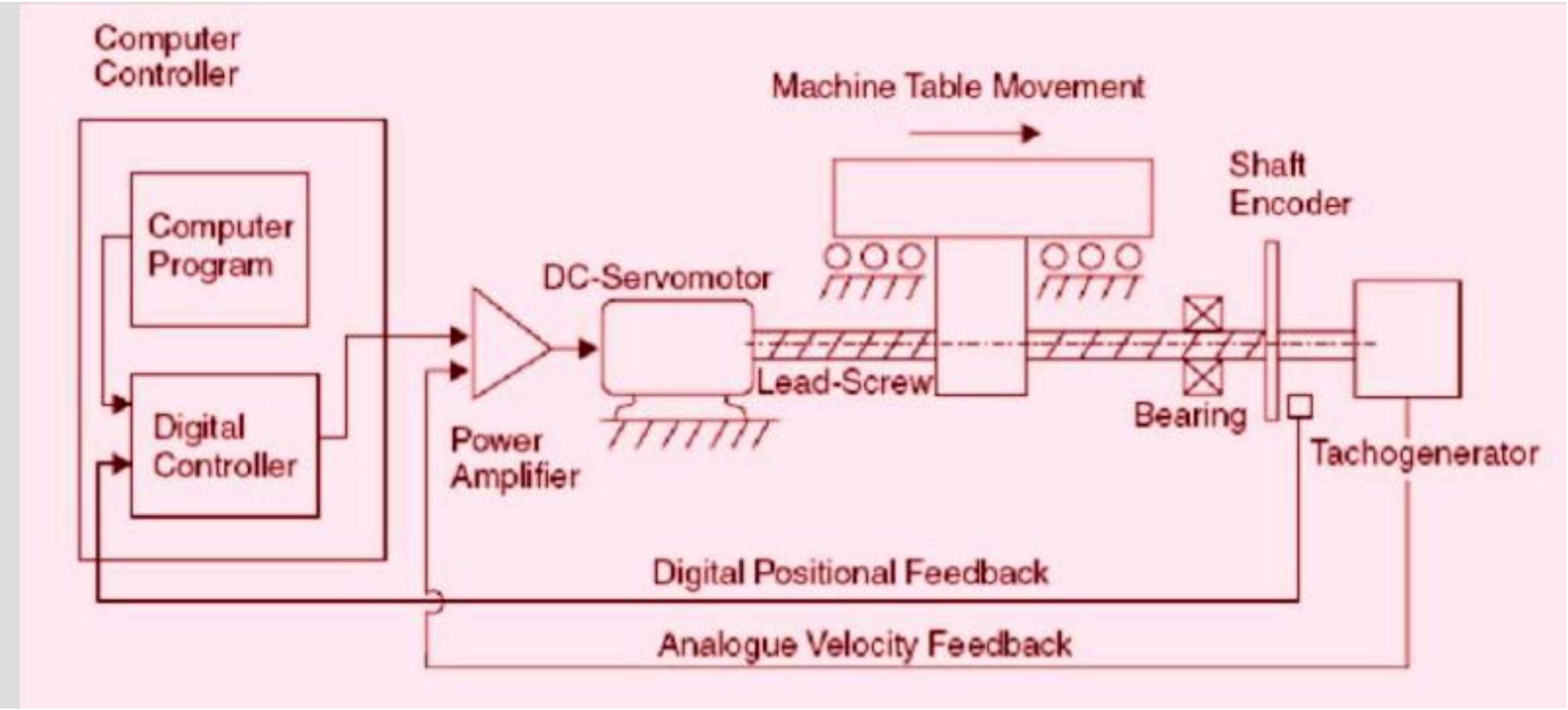
Dönen
ağırlıklar
yay
yavaş
hızlı
hızlı
yavaş
aç
kapa
Basınçlı
yağ
Güç
silindiri
Kontrol vanası
Pilot Silindir
aç
kapa
Buhar
Türbini
yük
Buhar
Kontrol Vanası





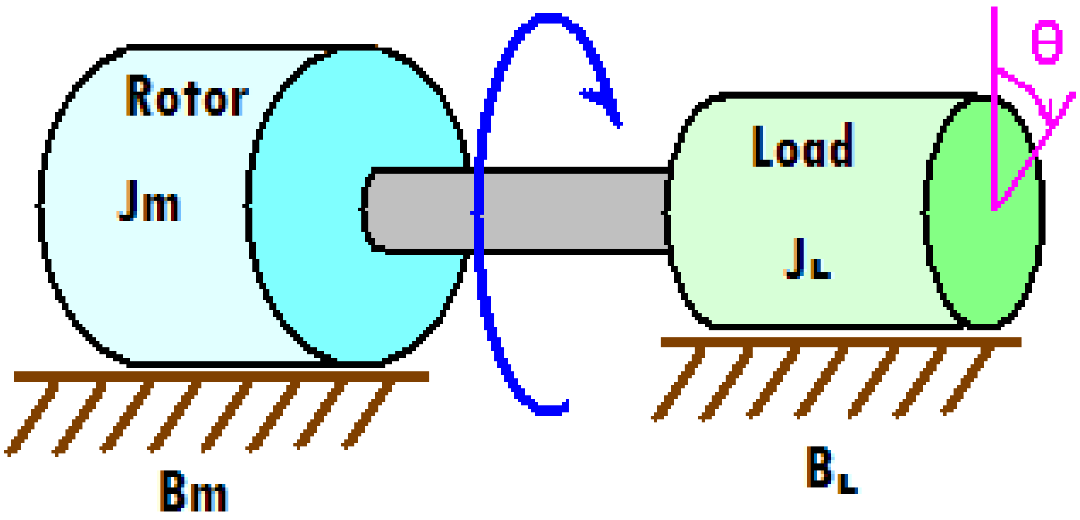


Computer Numerical Controlled Machine Tools



Looking at the Motor

- Mechanically:



θ Shaft Position

$\dot{\theta}$ Angular Velocity

$\ddot{\theta}$ Angular Acceleration

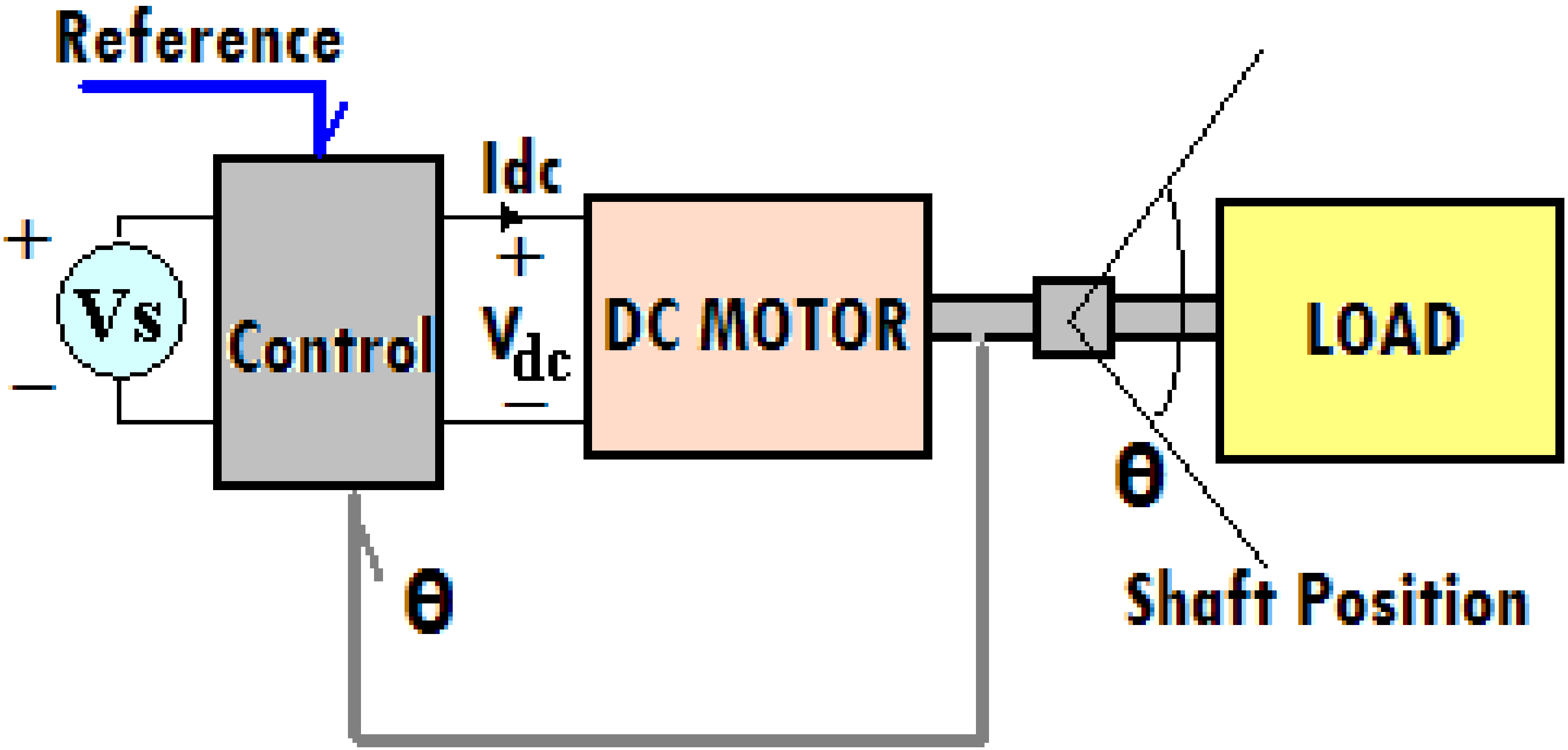
Mech. Torque, $T_m = J\ddot{\theta} + B\dot{\theta}$

J = Total Moment of Inertia of Motor/Load

B = Total Friction Force on Motor/Load

Physically, We Want:

- A 2nd Order SISO System with Input to Control Shaft Position:



PID Mathematically:

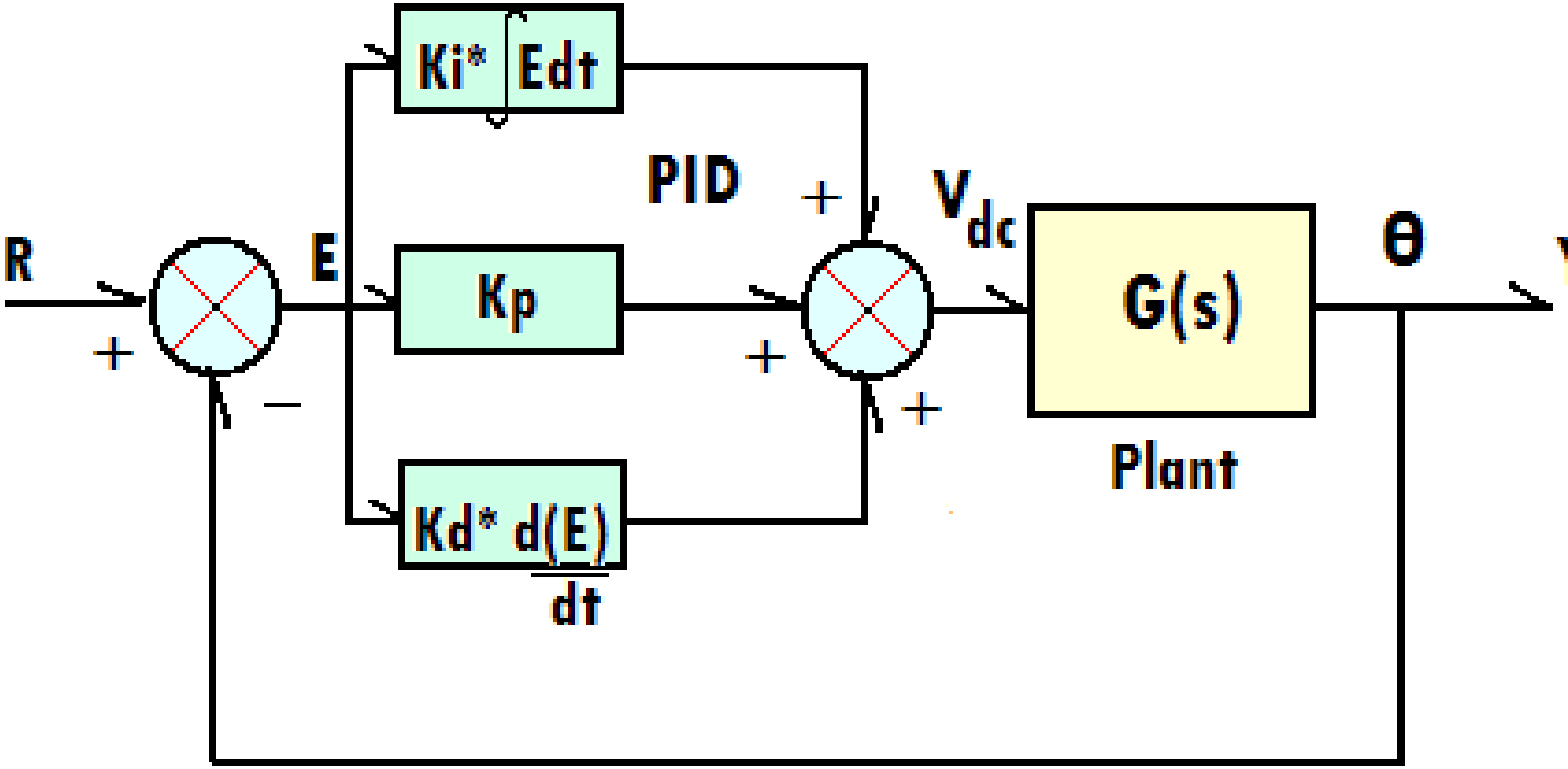
- Consider the input error variable, e(t):
  - Let p(t) = Kp*e(t)   {p proportional to e (mag)}
  - Let i(t) = Ki*∫e(t)dt   {i integral of e (area)}
  - Let d(t) = Kd* de(t)/dt {d derivative of e (slope)}

AND let Vdc(t) = p(t) + i(t) + d(t)

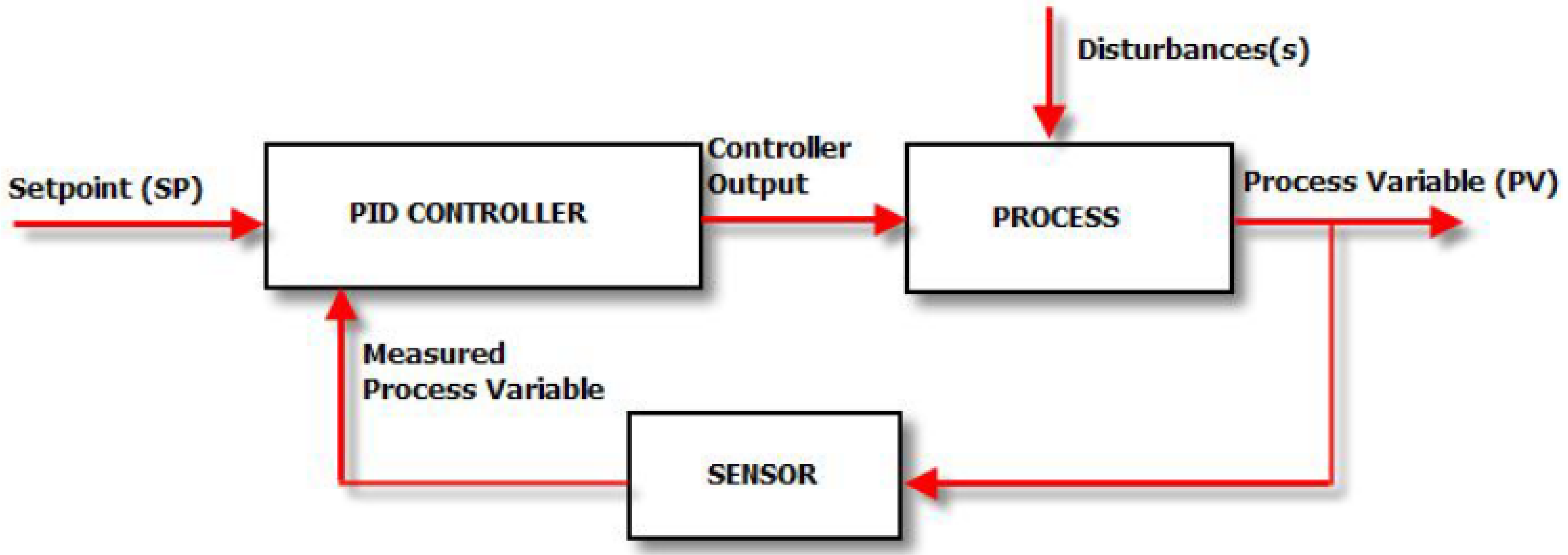
Then in Laplace Domain:

Vdc(s) = [Kp + 1/s Ki + s Kd] E(s)

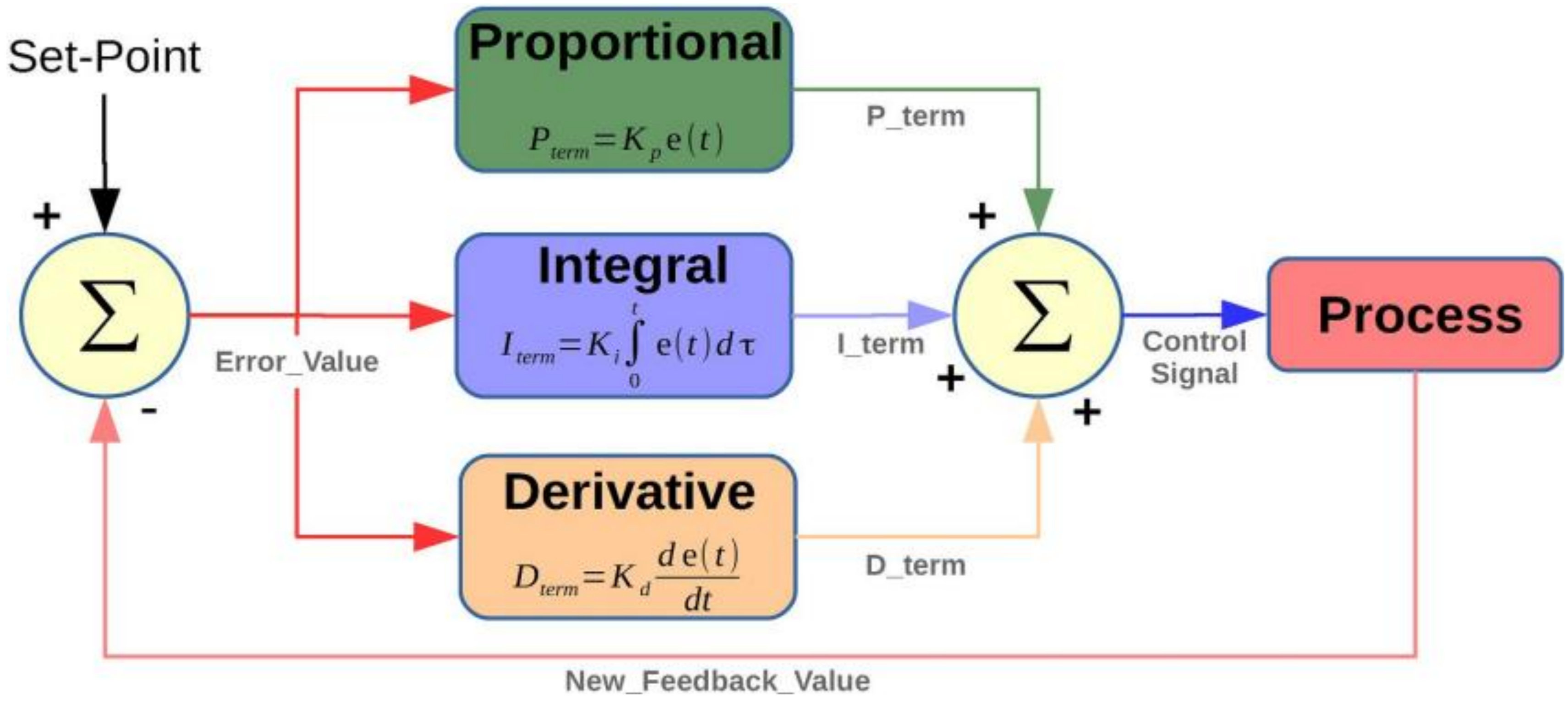
PID Block Diagram:



Block Diagram of a Process Under Control System



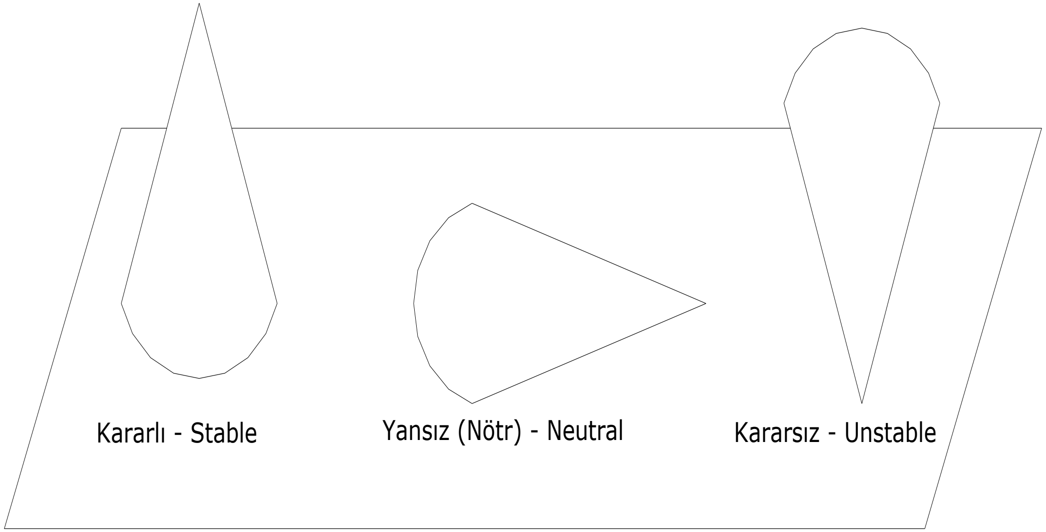
PID CONTROL



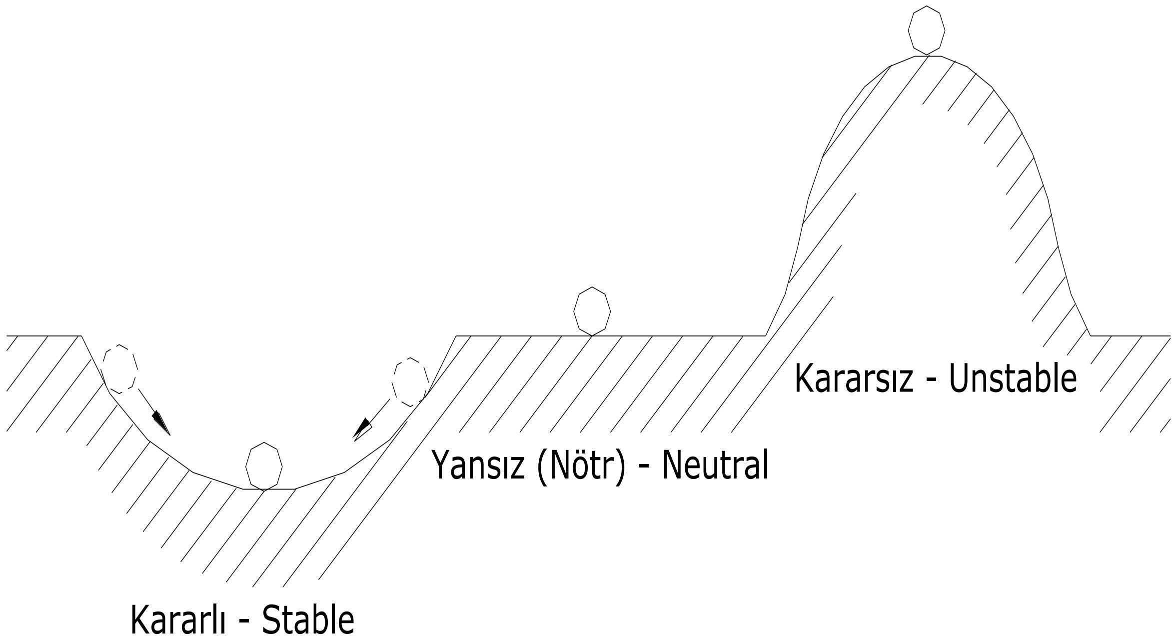
Set-Point
+
-
Σ
Error_Value
Proportional
$P_{term} = K_p e(t)$
P_term
Integral
$I_{term} = K_i \int_0^t e(t) d\tau$
I_term
Derivative
$D_{term} = K_d \frac{d e(t)}{dt}$
D_term
+
+
+
Σ
Control Signal
Process
New_Feedback_Value

Stability

- Definition 1: A system is stable if its impulse response approaches zero as time approaches infinity.
- Definition 2: A system is stable if every bounded input produces a bounded output.



A ball Example



Position Control

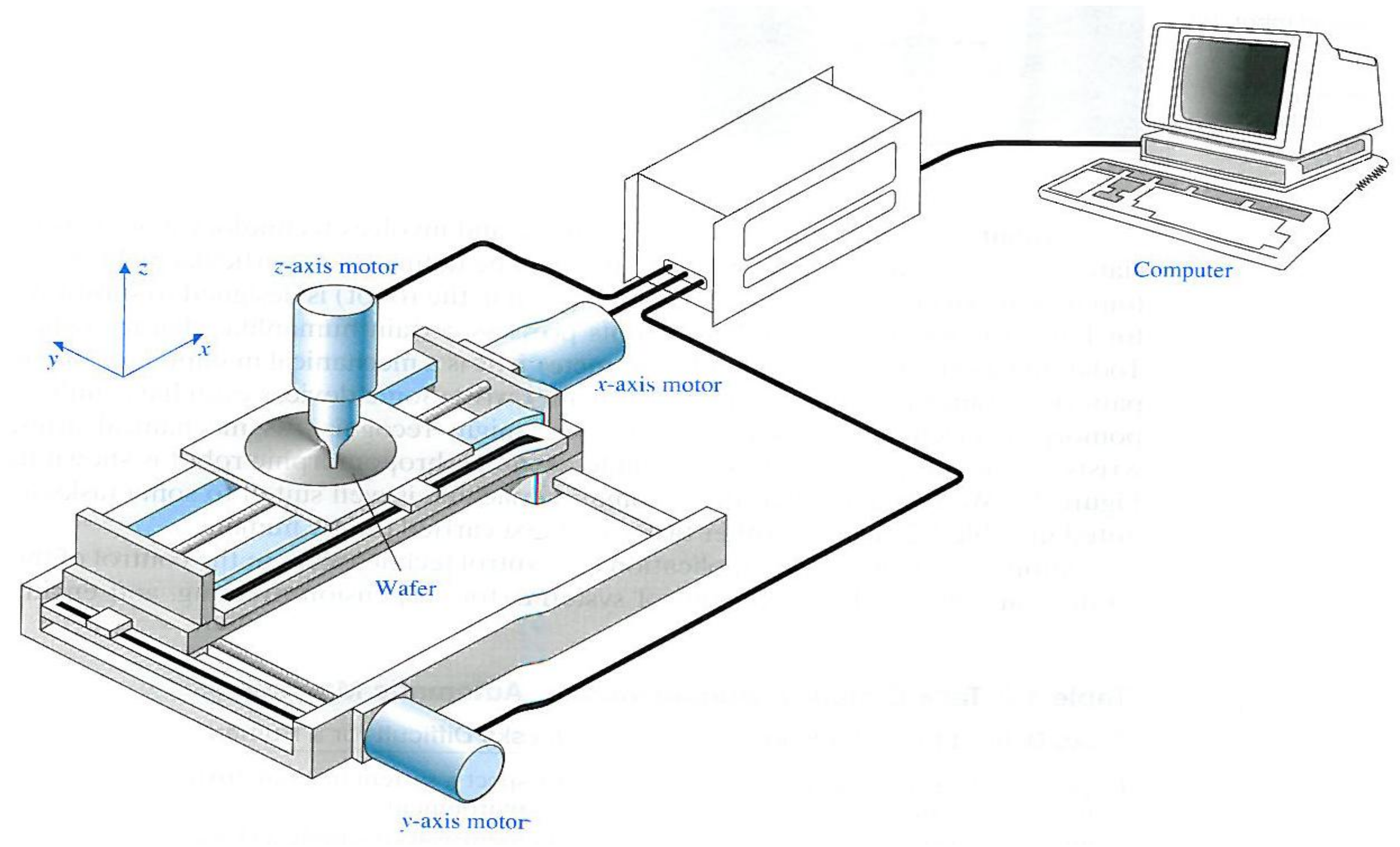


Fig. 1.8. Three axis control system

The system uses a specific motor to drive each axis to the desired position in the x,y,z axis, respectively.

More Control Systems Examples

- **Aerospace and Military Applications:**
  - Flights (Autopilot Control Applications ,Take off and Landing control),
  - Space Shuttles (Orbit Tracking Control Applications, Take off and Landing, etc.),
  - Unmanned vehicles,
  - Missile guidance and control, etc.

- **Noise and Active Vibration Control:**
  - Earthquake protection using active or semi-active vibration control,
  - Vibration suppression in aero plane wings and helicopter blades,
  - Automobile suspensions,
  - Noise canceling headphones.

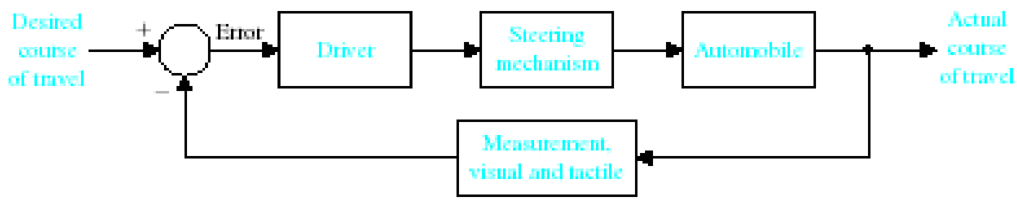
- **Computer systems:**
  - Position control systems for printers , CD/DVD drives and Hard drives.
  - Network and Internet traffic control.

- **Robotic Systems:**
  - Position, speed and force control for Assembly robots,
  - Balancing and motion control of humanoid robots ,
  - Precision control of Robots for Medical operations,
  - Mobile robots

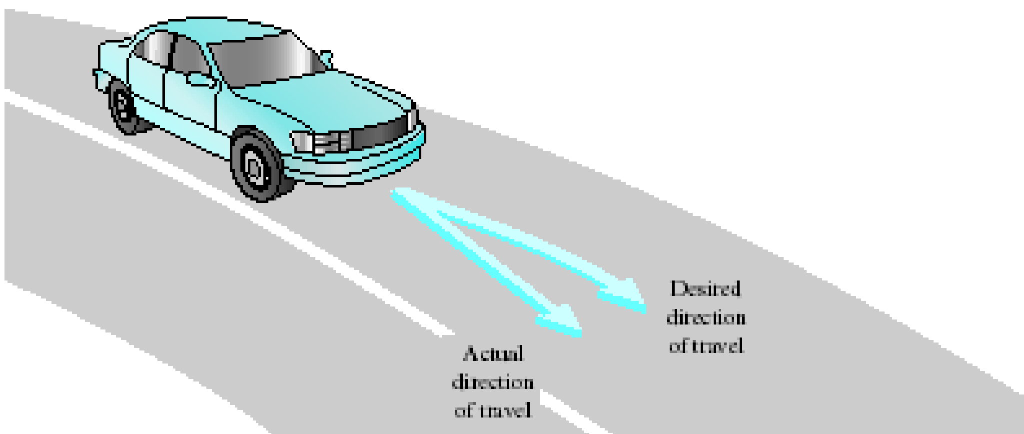
More Control Systems Examples (continued):

- **Biological systems** :
  - Insulin delivery control systems,
  - Tumor growth control, etc.
  - Artificial limbs, prosthetics,etc..
- **Automobile industry** :
  - Anti-lock brake system,
  - Automatic car parking assistance,
  - Cruise control, etc.
- **Manufacturing systems:**
  - CNCs,
  - Automatic packing machines,
  - Assembly lines.
- **Process control :**
  - Chemical processes,
  - Nuclear power plants,
  - Complex manufacturing processes
- **Power systems control:**
  - Voltage regulation in power networks for safe electricity delivery.

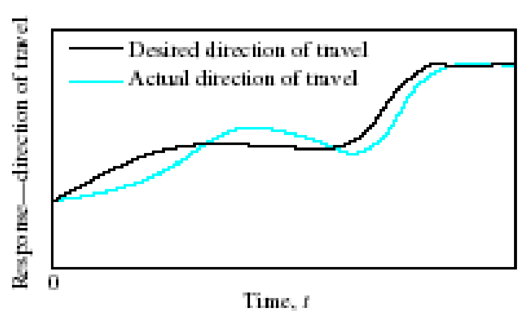
Examples of Modern Control Systems



(a)



(b)



(c)

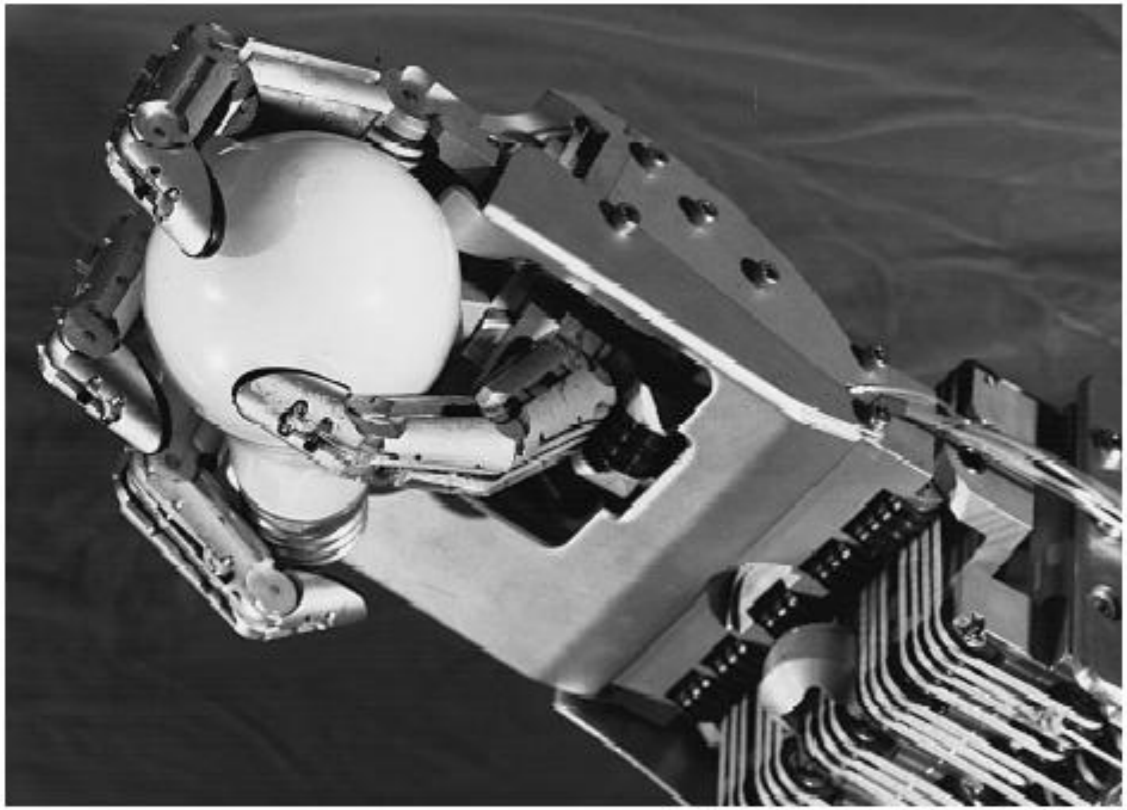
(a) Automobile steering control system.

(b) The driver uses the difference between the actual and the desired direction of travel

to generate a controlled adjustment of the steering wheel.

(c) Typical direction-of-travel response.

Examples of Modern Control Systems



The Utah/MIT Dextrous Robotic Hand: A dextrous robotic hand having 18 degrees of freedom, developed as a research tool by the Center for Engineering Design at the University of Utah and the Artificial Intelligence Laboratory at MIT. It is controlled by five Motorola 68000 microprocessors and actuated by 36 high-performance electropneumatic actuators via high-strength polymeric tendons. The hand has three fingers and a thumb. It uses touch sensors and tendons for control.
(Photograph by Michael Milochik. Courtesy of University of Utah.)

Servo Systems: In feedback control, it applies only to systems where the feedback or error-correction signals help control mechanical position, speed or other parameters. The system reference input is variable and the output follows the reference input.

Regulator Systems: A *regulator or regulating system is a feedback control system in which* the reference input or command is constant for long periods of time, generally for the entire time interval during which the system is operational. Such an input is known as *set point. The main* objective is to maintain the actual output at the desired value in the presence of disturbances.

ROBOT

The International Federation of Robotics (norm ISO/TR 8373) defines:

> A manipulating industrial robot is an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications.

The number of joints of a manipulator determines as well, its number of *degrees of freedom* (*DOF*) —typically 6 DOF —.

- 3 determine the position of the end of the last link in the Cartesian space
- 3 more specify its orientation.

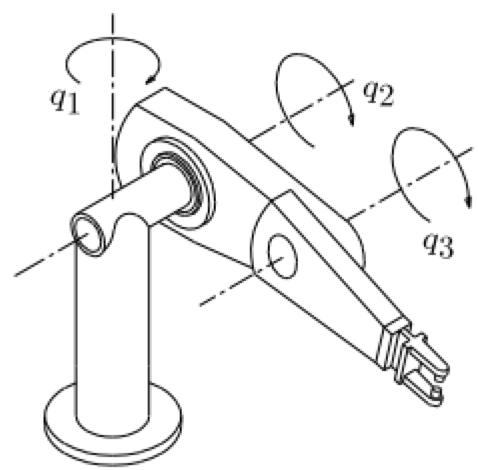


Figure 1: Robot manipulator.

Control specifications

Definition of control objectives:

- Stability
- Regulation
- Trajectory tracking (motion control)
- Optimization.

- *Stability*. Consists in the property of a system by which it goes on working at certain regime or ‘closely’ to it ’for ever’.

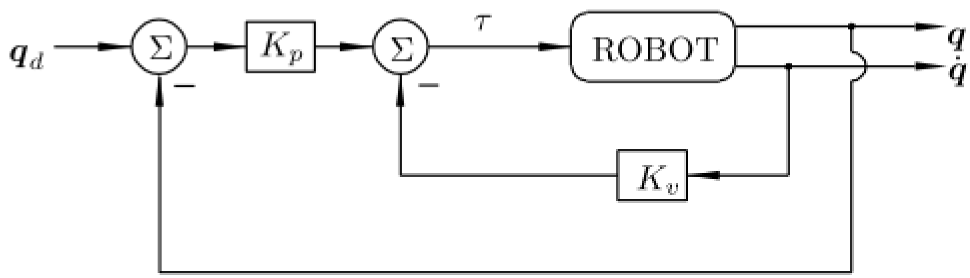
  - *Lyapunov* stability theory.
  - *input-output* stability theory.

  In the case when the output $\boldsymbol{y}$ corresponds to the joint position $\boldsymbol{q}$ and velocity $\dot{\boldsymbol{q}}$.

- *Regulation* “Position control in joint coordinates”

- *Trajectory tracking* “Tracking control in joint coordinates”

Ch. 6. Velocity feedback proportional control and PD control



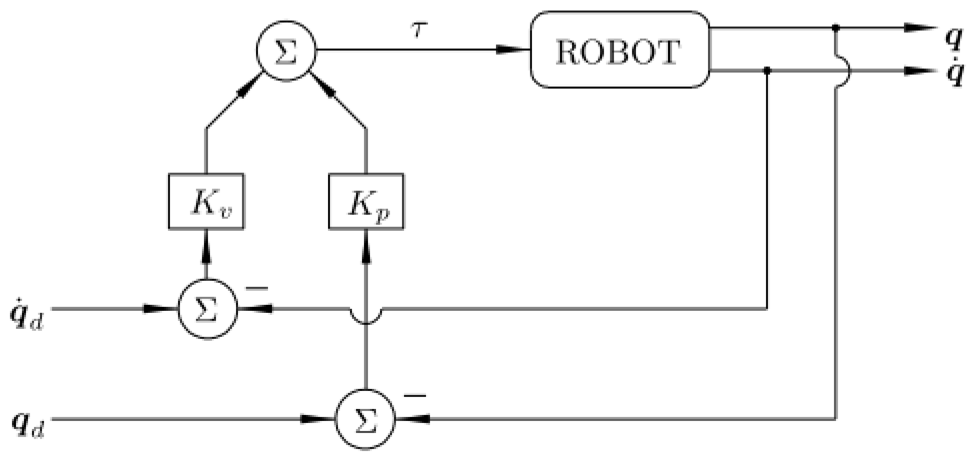
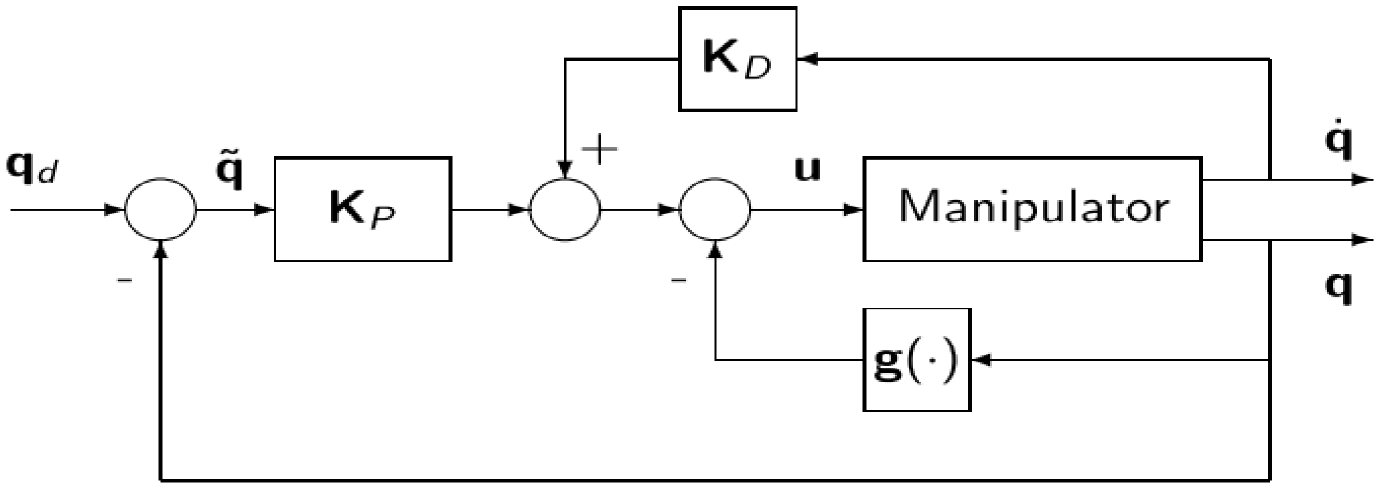
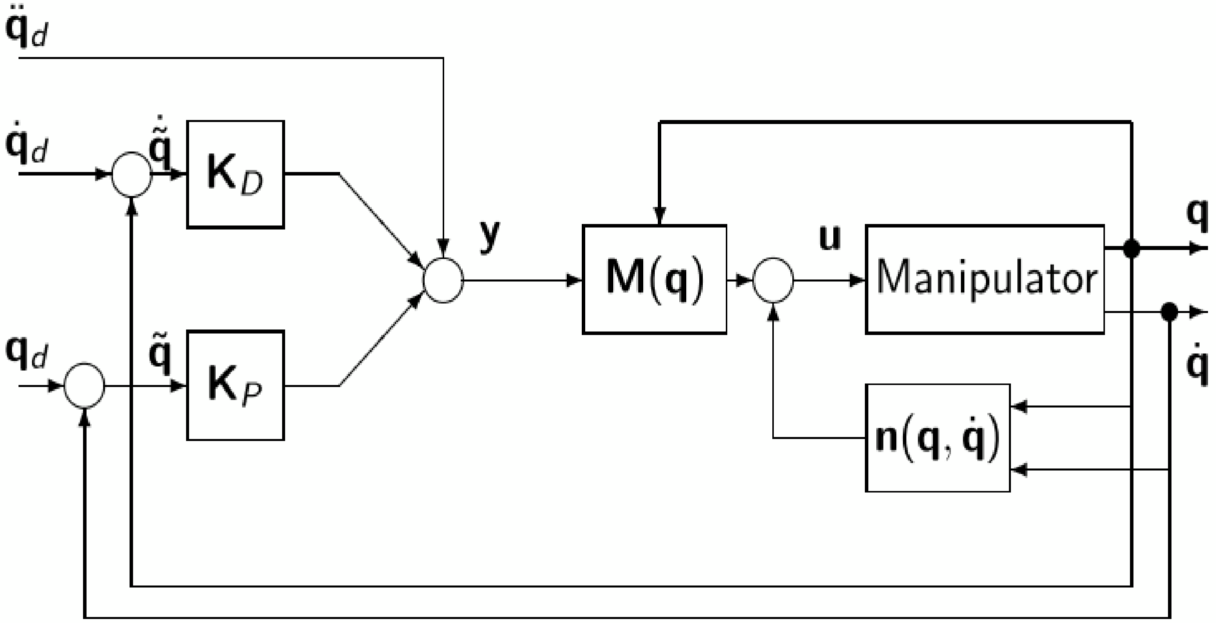


Figure 44: PD Control.

PD controller with gravity compensation



Inverse dynamics control



The figure depicts the graphs of above reference trajectories against time.

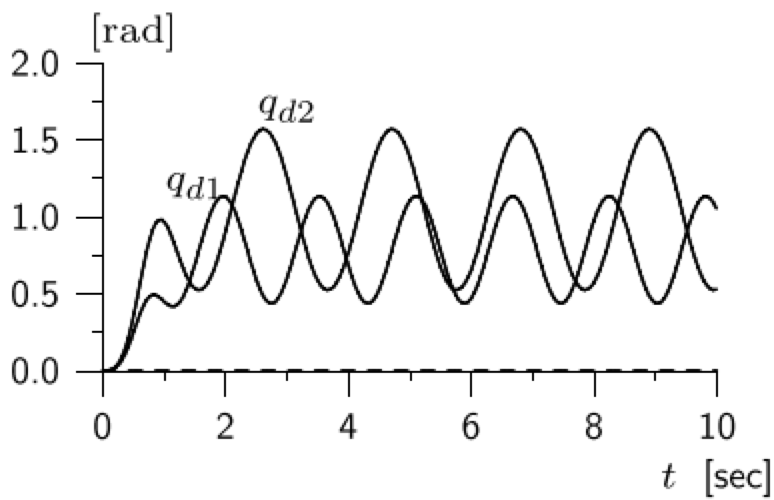


Figure 37: Desired reference trajectories.

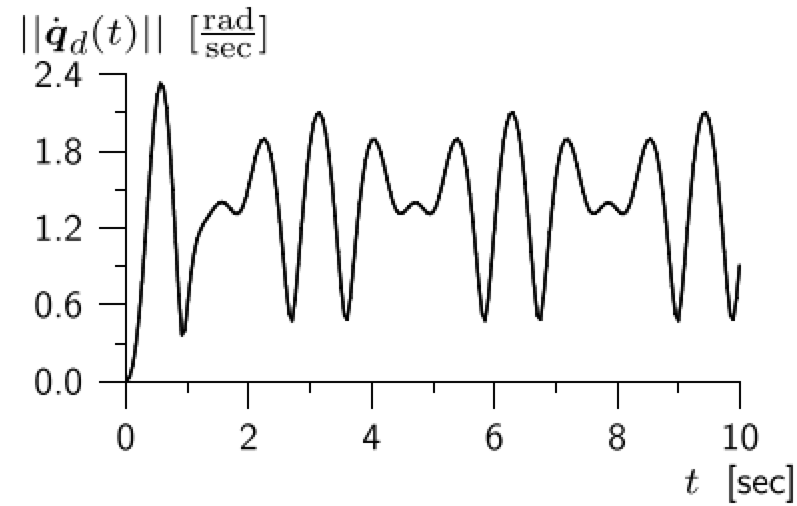


Figure 39: Norm of the desired reference velocities vector.

$$
\begin{aligned}
\dot{q}_{d1} &= 6b_1 t^2 e^{-2.0\ t^3} + 6c_1 t^2 e^{-2.0\ t^3} \sin(\omega_1 t) + [c_1 - c_1 e^{-2.0\ t^3}] \cos(\omega_1 t)\omega_1, \\
\dot{q}_{d2} &= 6b_2 t^2 e^{-2.0\ t^3} + 6c_2 t^2 e^{-2.0\ t^3} \sin(\omega_2 t) + [c_2 - c_2 e^{-2.0\ t^3}] \cos(\omega_2 t)\omega_2 \, . \\
& \text{in } [\,\text{rad/sec}\,].
\end{aligned}
\tag{14}
$$

Reference accelerations:

$$\begin{aligned}
\ddot{q}_{d1} &= 12b_1te^{-2.0\ t^3} - 36b_1t^4e^{-2.0\ t^3} + 12c_1te^{-2.0\ t^3}\mathrm{sen}(\omega_1 t) \\
&- 36c_1t^4e^{-2.0\ t^3}\mathrm{sen}(\omega_1 t) + 12c_1t^2e^{-2.0\ t^3}\cos(\omega_1 t)\omega_1 \\
&- [c_1 - c_1e^{-2.0\ t^3}]\mathrm{sen}(\omega_1 t)\omega_1^2 \qquad [\mathrm{rad}\ /\ \mathrm{sec}^2]\,,
\end{aligned}$$

$$\begin{aligned}
\ddot{q}_{d2} &= 12b_2te^{-2.0\ t^3} - 36b_2t^4e^{-2.0\ t^3} + 12c_2te^{-2.0\ t^3}\sin(\omega_2 t) \\
&- 36c_2t^4e^{-2.0\ t^3}\sin(\omega_2 t) + 12c_2t^2e^{-2.0\ t^3}\cos(\omega_2 t)\omega_2 \\
&- [c_2 - c_2e^{-2.0\ t^3}]\sin(\omega_2 t)\omega_2^2 \qquad [\mathrm{rad}\ /\ \mathrm{sec}^2]\ .
\end{aligned} \tag{15}$$

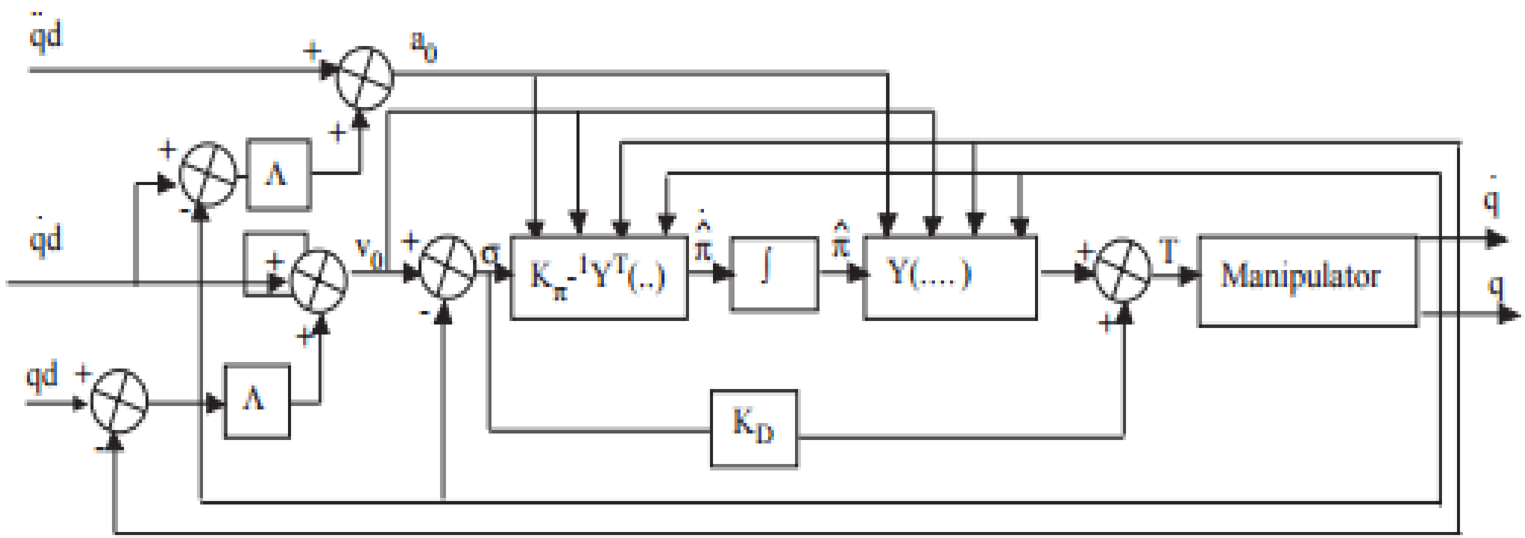


Figure 1. Block diagram of adaptive control (Sciavicco and Siciliano, 1996).

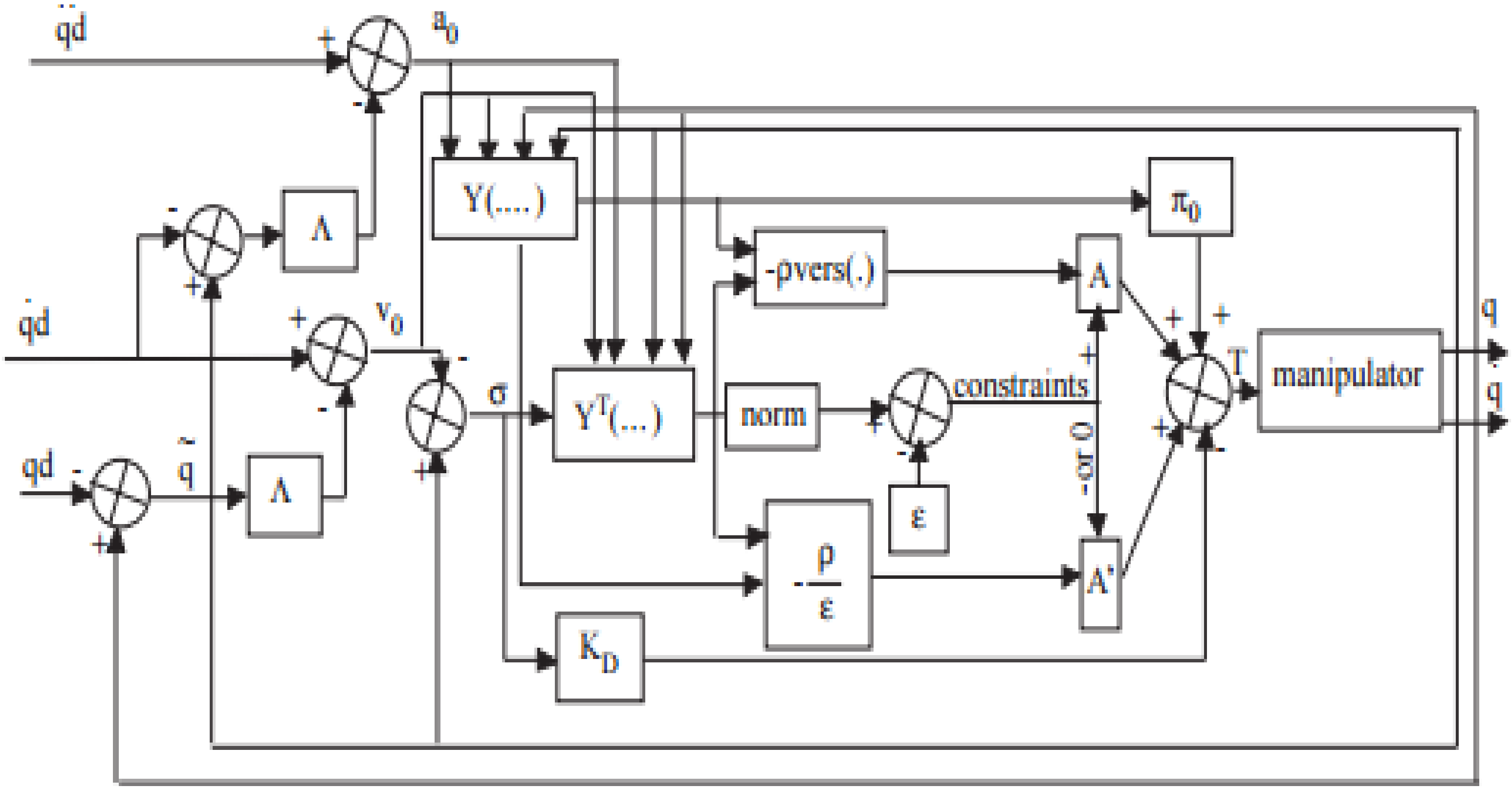


Figure 2. Block diagram of the robust control law.