Control problem formulation

Preliminaries and notation

A general feedback control system configuration

Tracking and regulator problem formulation

Examples of control systems (open-loop and closed-loop)

… from the dictionary

What do we mean by **control**?

In current Italian, in most cases the term **control** is used as a synonym for verification, monitoring.

Here we are interested in the meaning similar to the English term **control**.

Current definitions from some non-specialist dictionaries:

- The action or set of actions to be taken in order to drive a physical quantity to a certain value or a sequence of values.
- Device to which is entrusted the government of the value of a physical quantity.
- Automatic device for controlling or adjusting the operation of a machine or plant.

… from the dictionary

From the dictionary, again:

physical quantity: any quantity subject to measurement.

It is intuitive and straightforward to associate physical quantities to an apparatus, a process, ... in general, to a system.

We see that the basic definitions of **control** are strictly related to the notion of **system**.

To start with, we are not going to give a rigorous, axiomatic definition of system.

Instead, an informal definition will do for our purpose.

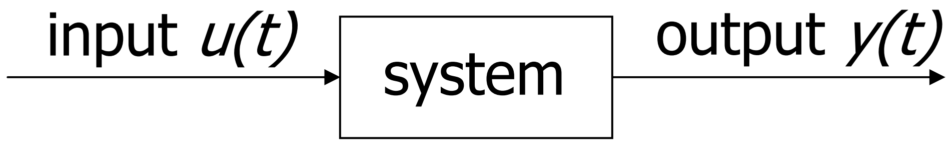
Informal definition of system

System literary means **composition**. From Greek, a system is a "whole compounded of several parts or members‟.

A system is a collection of one or more devices, processes, or computer-implemented algorithms that operates on an input signal $u(t)$ to produce an output signal $y(t)$.

A system is a set of interacting or interdependent entities forming a set of relationships.

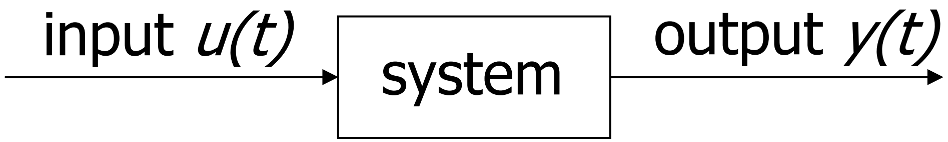
In mathematical modeling terms a system is a function that transforms or maps the **input** signal/sequence, to a new **output** signal/sequence



Informal definition of system

The inputs *u(t)* (also **causes**, **excitations**) are applied to the input terminal.

The outputs *y(t)* (also **effects**, **responses**) are measurable at the output terminals.

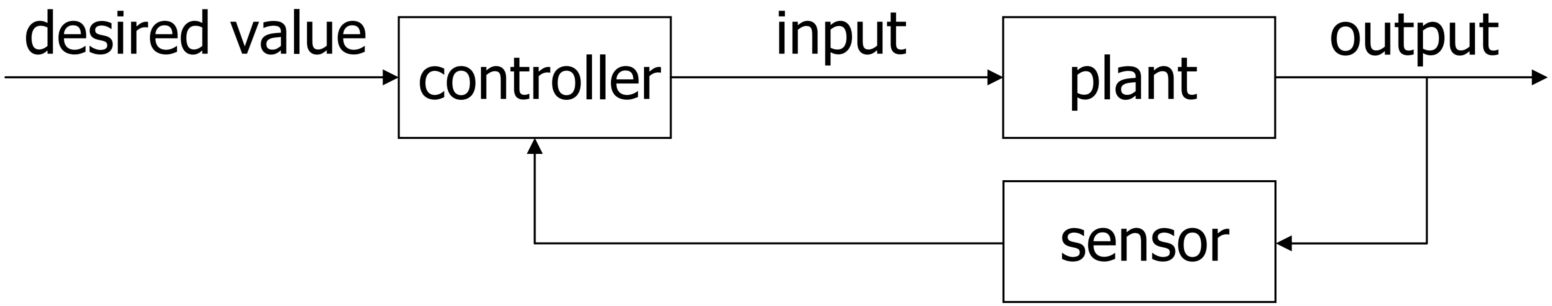


Basic components of control systems

A control system is a dynamic system which behaves in a certain prescribed way, in general without human intervention.

The basic components of a control system are:

- the **plant**, which is the system to be controlled
- one or more **sensors**, which give information about the plant
- the **controller**, which compares the measured values to their desired values and provides the input variables to the plant

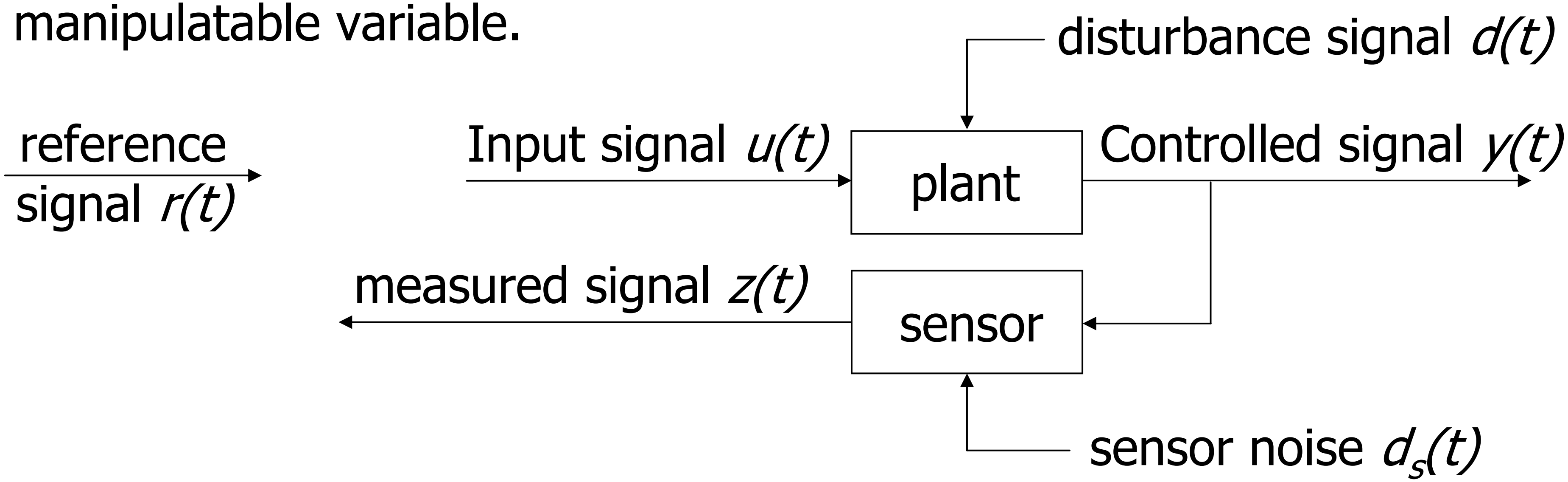


Tracking and regulator problems

Here we recall an important class of control problems: **tracking problems**.

The plant, which cannot be modified by the designer, is surrounded by the following signals:

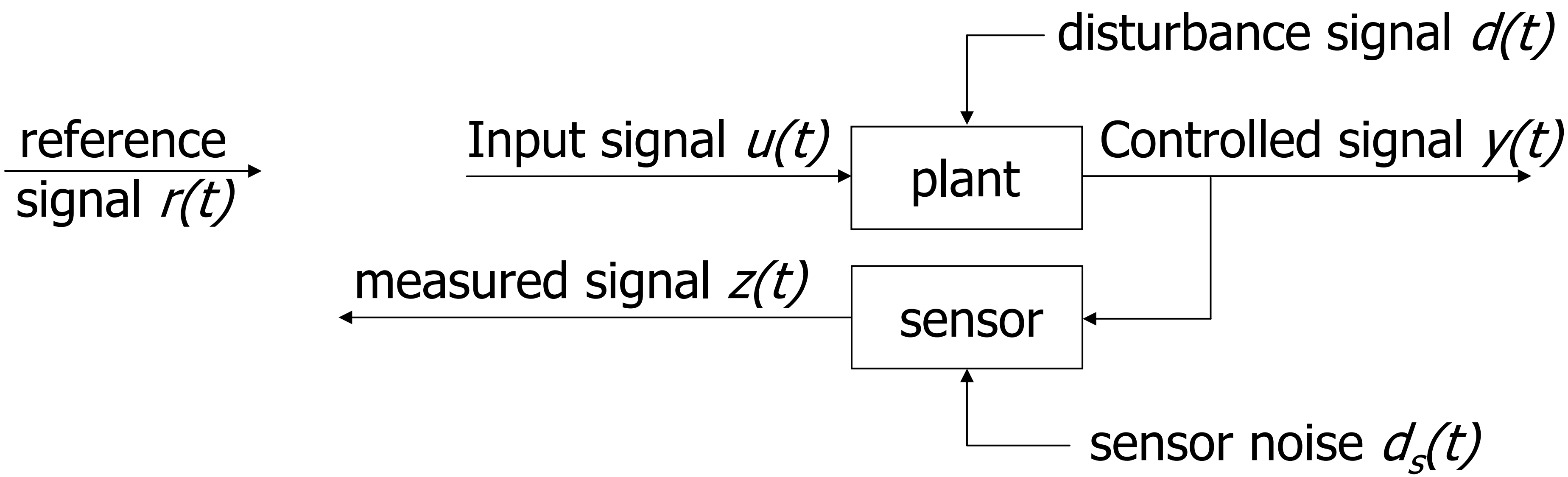
- the **input signal** *u(t)*, which influences the plant and is a manipulatable variable.



Tracking and regulator problems

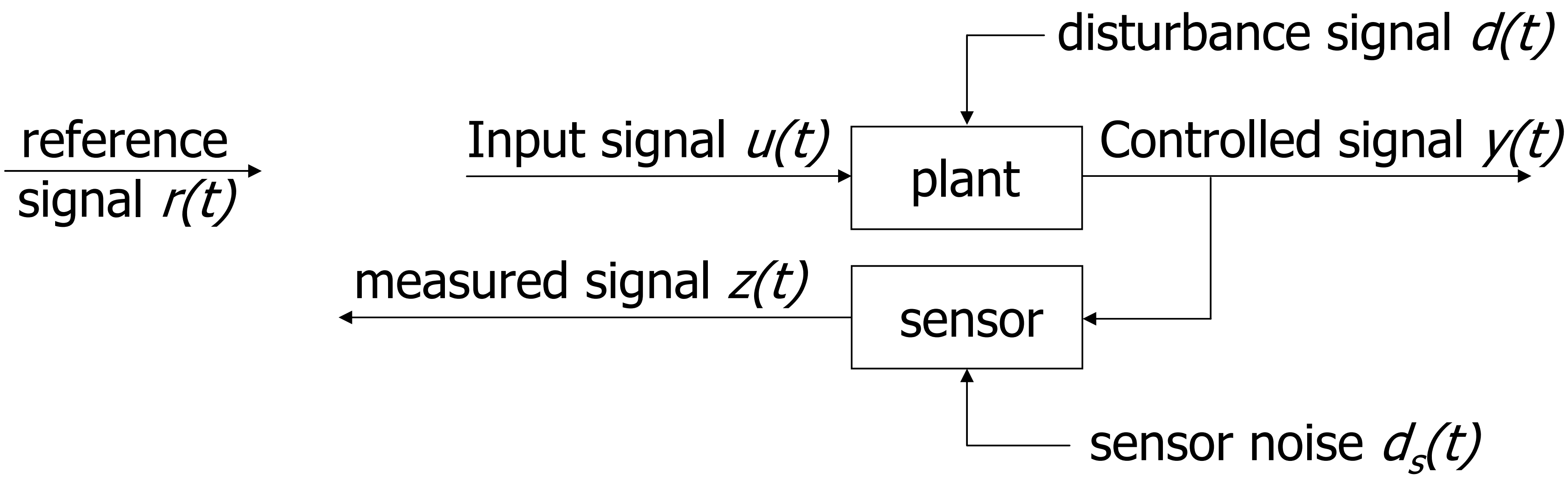
- the **disturbance signal** $d(t)$, which influences the plant and cannot be manipulated.

- the **measured signal** $z(t)$, which is measured by means of a sensor and contains information about the state of the plant.



Tracking and regulator problems

- the **sensor noise** $d_s(t)$, which affects the measured signal.
- the **controlled signal** $y(t)$, which is the signal under control.
- the **reference signal** $r(t)$, which gives the prescribed values of the controlled signal.



Tracking and regulator problems

We are now ready to give the following informal formulation of the considered control problem (tracking):

For a given reference signal $r(t)$, find a suitable input signal $u(t)$ such that the controlled signal $y(t)$ tracks the reference signal $r(t)$, i.e.:

$$y(t) \approx r(t), \quad t \geq t_0$$

Where t_0 is the time at which the control signal feeds the plant.

As we shall see, a pactical constraint is that the input signal $u(t)$ cannot take any values.

Tracking and regulator problems

In the design of tracking systems, the following aspects must be taken into account:

- the disturbances affect the plant in a way that is not predictable.
- the plant parameters may be uncertain and time-varying.
- the measured signal is affected by sensor noise.
- the range of values over which the input signal $u(t)$ is allowed to vary is limited.

Tracking and regulator problems

An important class of control problems is the one where the **reference signal is constant**.

In this case, the reference signal is simple referred to as the **set point** of the system and the control problems take the name of **regulator** problems.

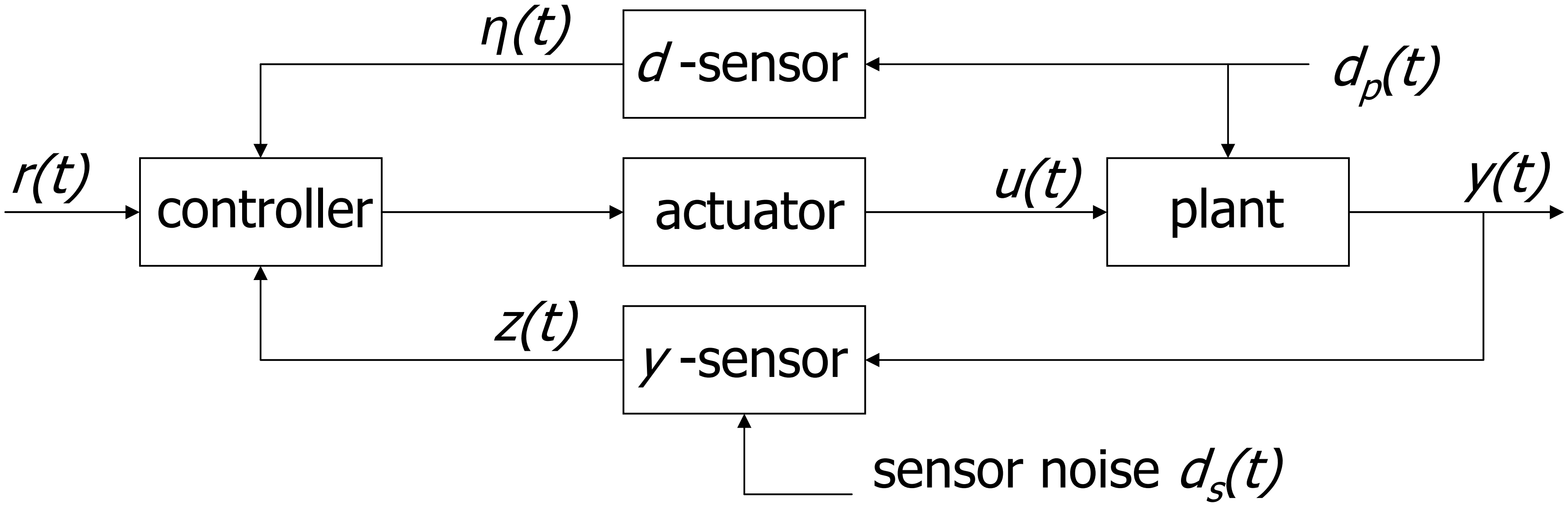
In regulator problems, the main task is to mantain the controlled signal at the set point, in the presence of the disturbances that affect the plant.

Output feedback control systems configurations

A layout of a general feedback control system is represented below.

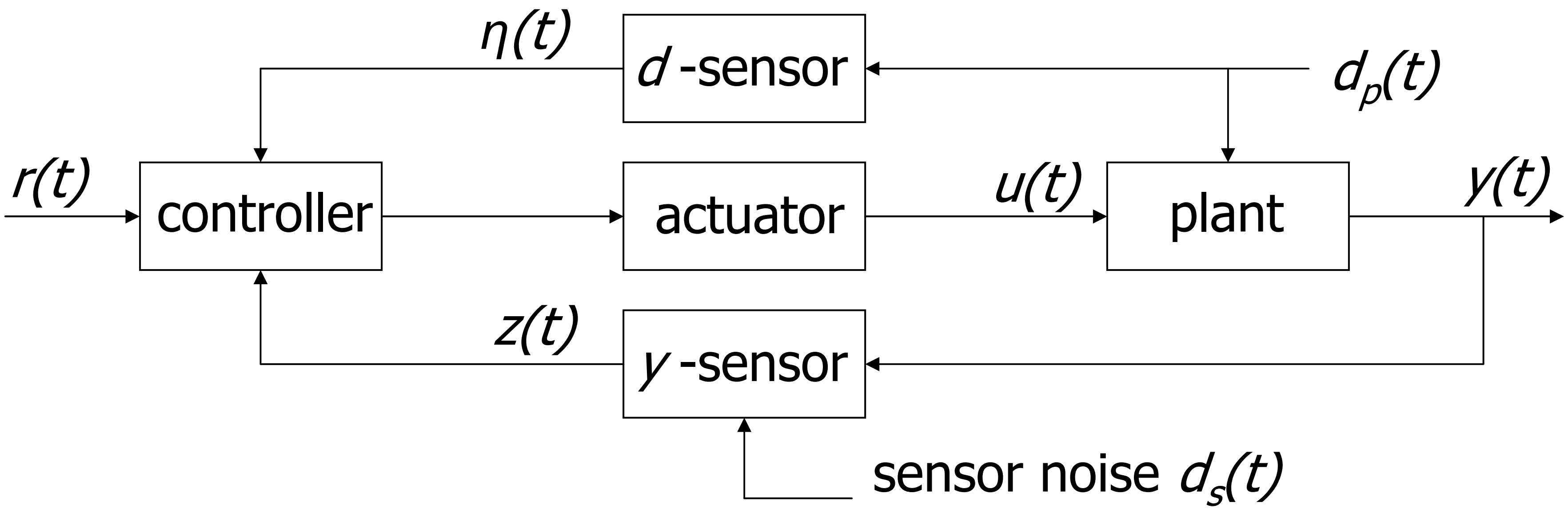
The components of a the control system are:

- The **plant**: is the system to be controlled.
- One or more **sensors**: give information about the plant and, possibly, the disturbances.



Output feedback control systems configurations

- The **controller**: compares the measured values to their desired values and provides the input variables to the plant.
- The **actuator**: provides the input signal $u(t)$ suitably amplified.

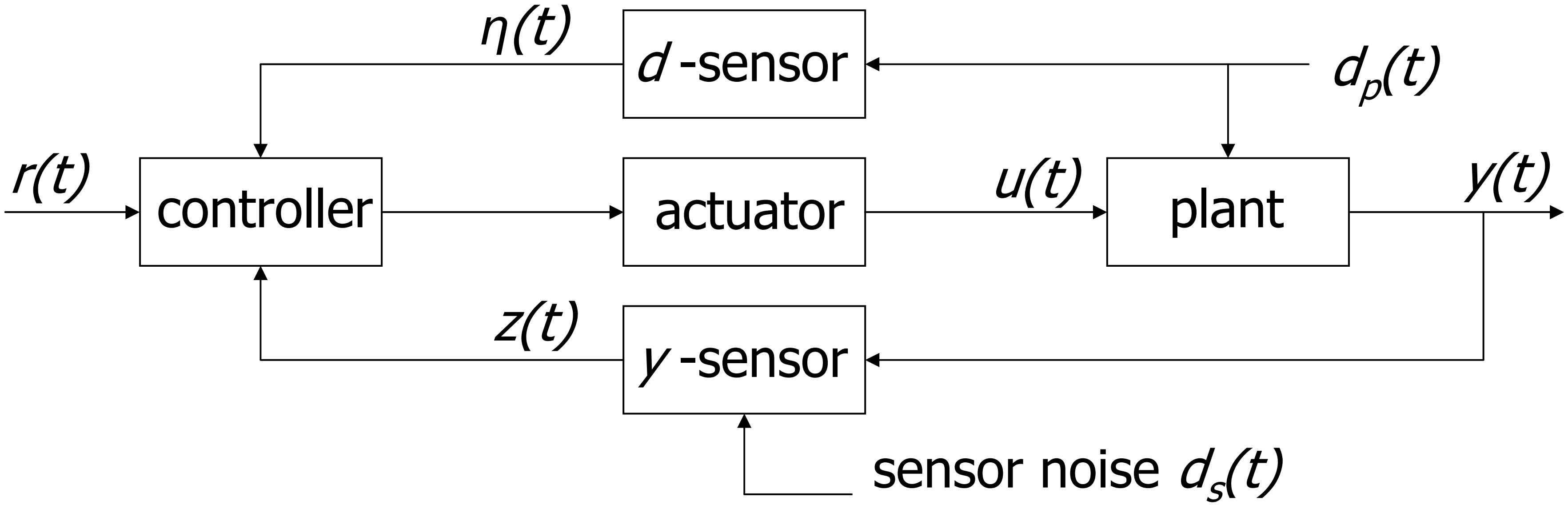


Output feedback control systems configurations

The main signal of interest are:

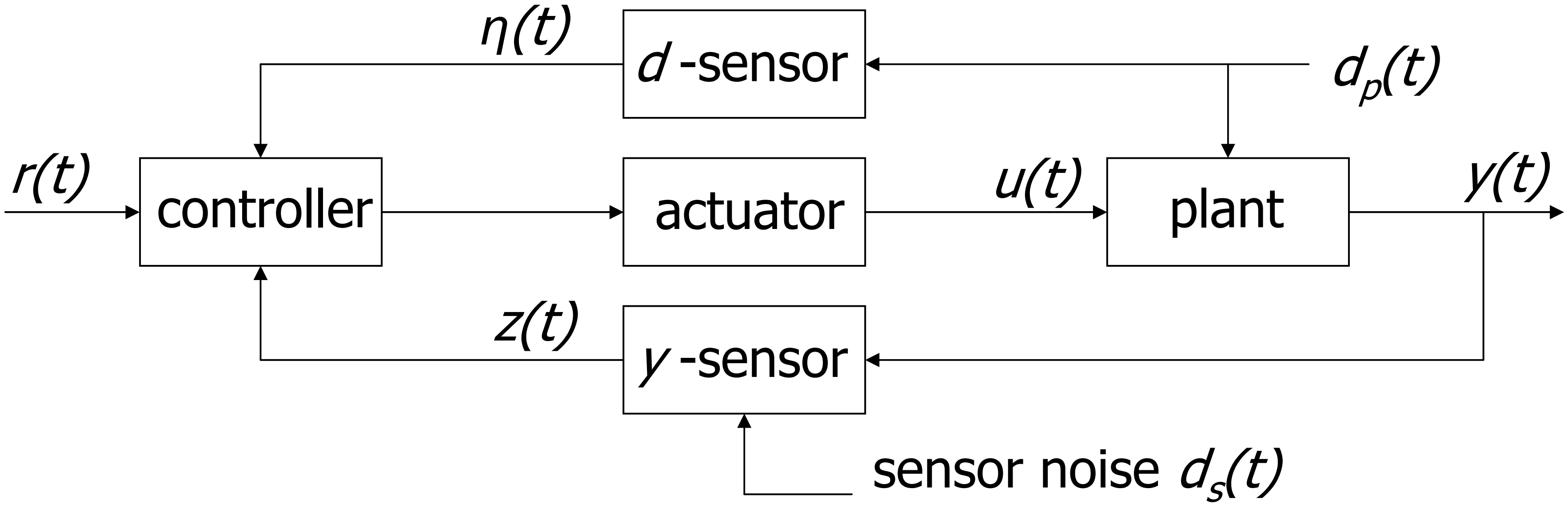
- The **reference signal** *r(t)* : gives the prescribed values of the controlled signal.

- The **input signal** *u(t)* : influences the plant and is a manipulatable variable.



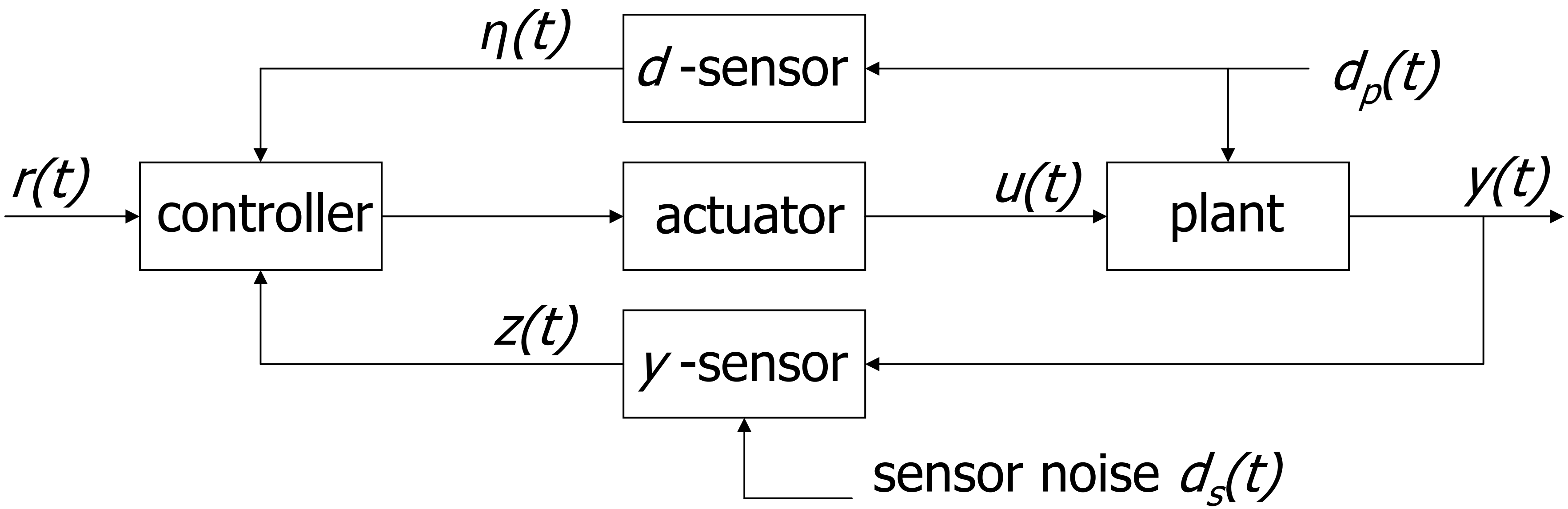
Output feedback control systems configurations

- The **controlled signal** $y(t)$: is the signal under control.
- the **disturbance signal** $d_p(t)$: influences the plant and cannot be manipulated.
- the **sensor noise** $d_s(t)$: affects the measured signal.



Output feedback control systems configurations

- The **measured signal** $z(t)$: is measured by means of a sensor and contains information about the state of the plant.
- Possibly, the **measured signal** $\eta(t)$: is measured by means of a sensor and contains information about the plant disturbance.

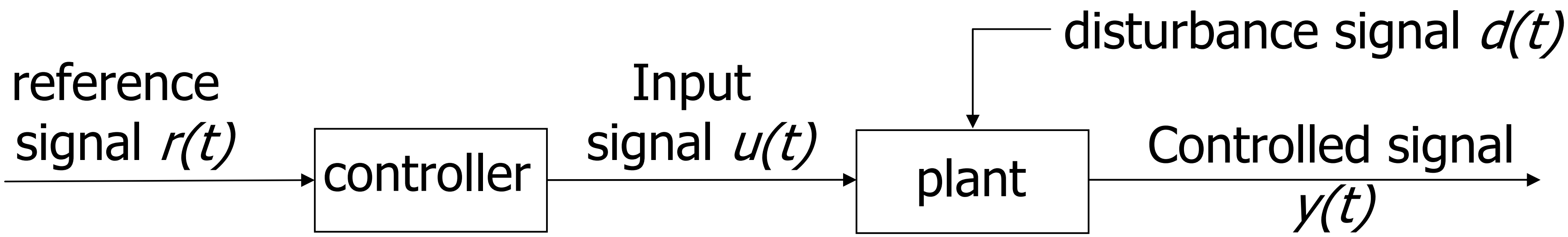


Open-loop controller

The input signal to the plant is provided by a device which is usually called **controller**.

Open-loop controllers provide the input signal to the plant on the basis of past and present values of the **reference signal only**.

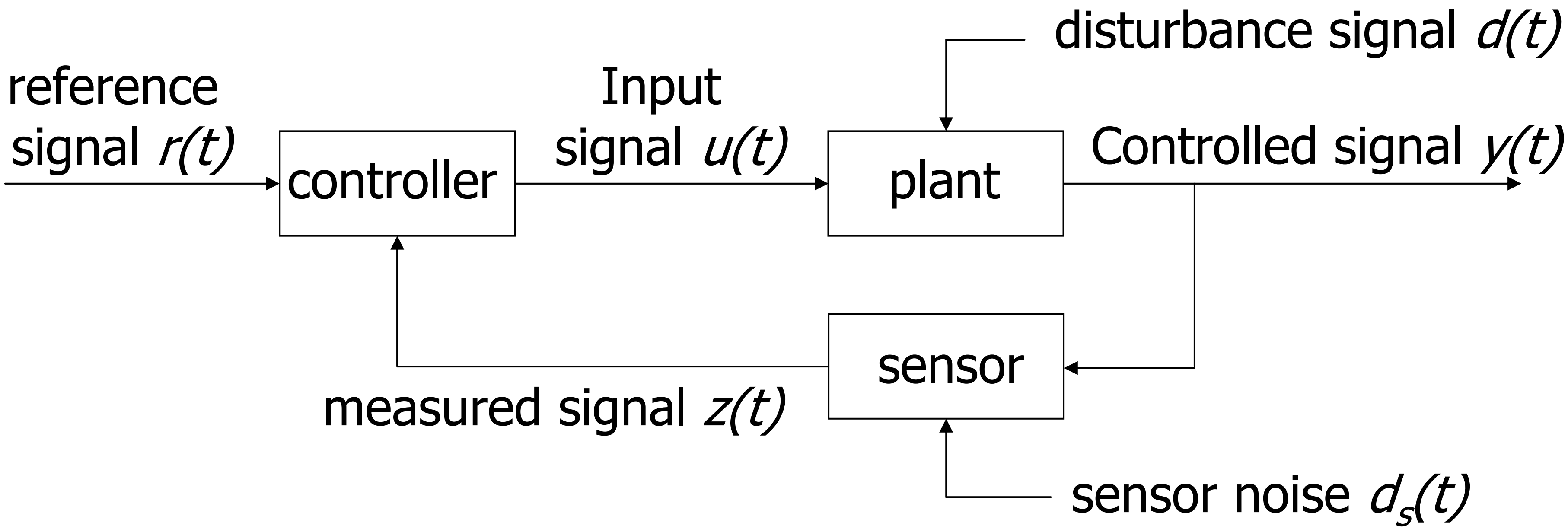
Open-loop controllers have no access to any information about the plant (disturbance, varying parameters) except for what is known before the control signal is applied.



Closed-loop controller

Closed-loop controllers exploit the information about the plant contained in the measured signal *z(t)*.

Closed-loop controllers provide the input signal to the plant on the basis of past and present values of **both** the **reference signal** and the **measured signal**.

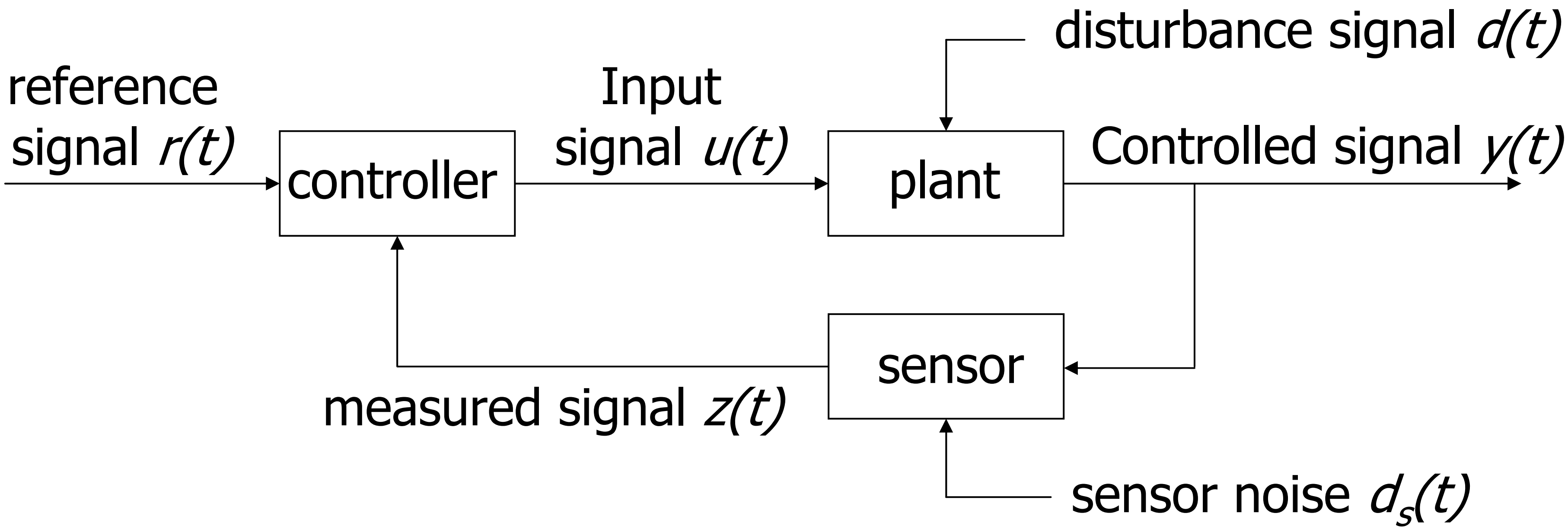


Closed-loop controller

Closed-loop controllers are more powerful than open-loop controller.

Closed-loop controllers are able to reduce the effects of the disturbances and compensate for plant parameters uncertainty and variations.

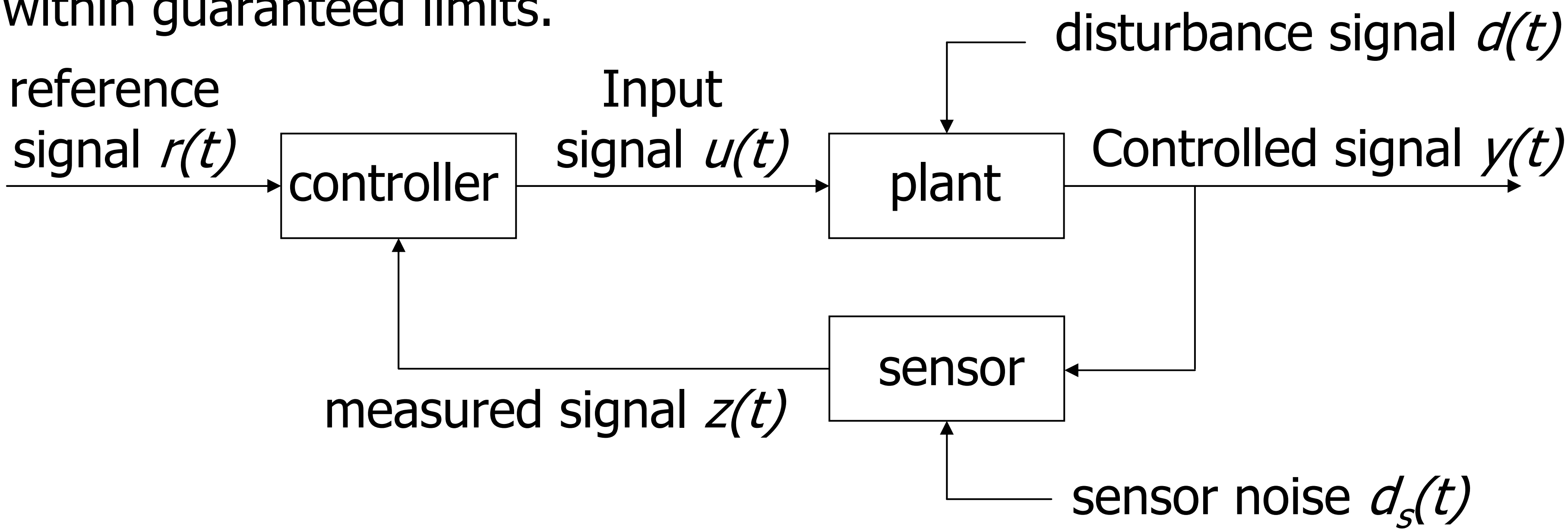
The plant and the controller is referred to as the **control system**.



Closed-loop controller

It is not true that the sole purpose of the feedback is to alter the dynamics of the plant (an open-loop controller could serve the purpose equally well).

The main purpose of feedback is to take into account plant uncertainties and ensure that performance specifications are met within guaranteed limits.

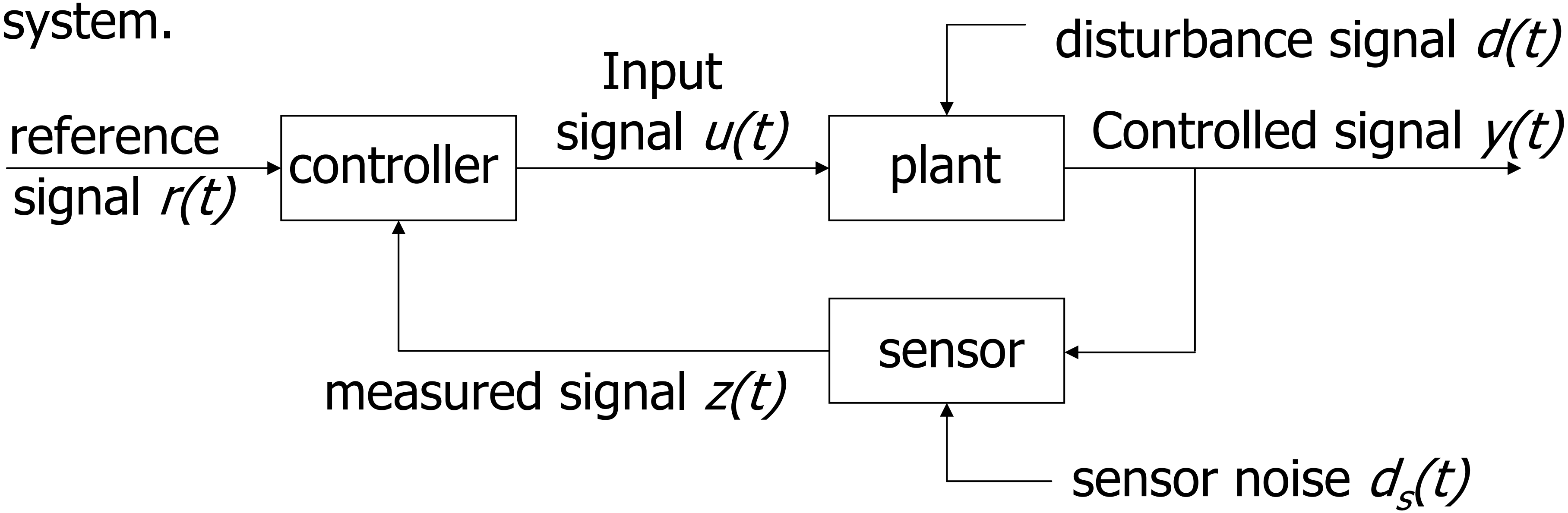


Closed-loop controller

In the design of controllers for specific plants, a mathematical model which represents the plant is used.

Any model can at best only be an approximation of the real plant.

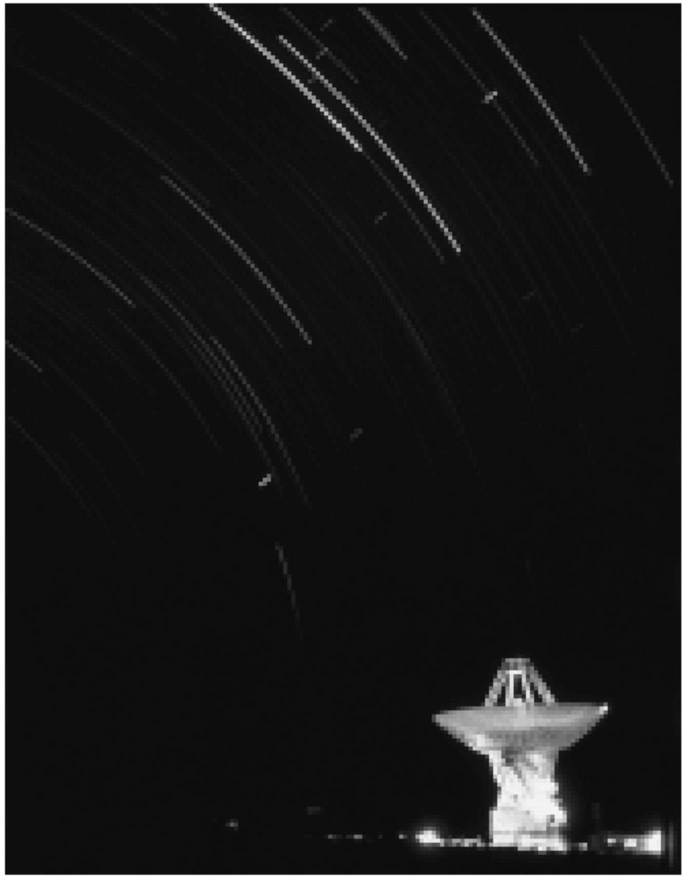
The mismatch between the model and the plant may result in controllers which give rise to stability problems in the closed-loop system.



Ex1: Antenna azimuth position control system

In this example we describe the problem of controlling the **antenna azimuth position**.

The search for extraterrestrial life is being carried out with radio antennas like the one pictured here. A radio antenna is an example of a system with position controls.



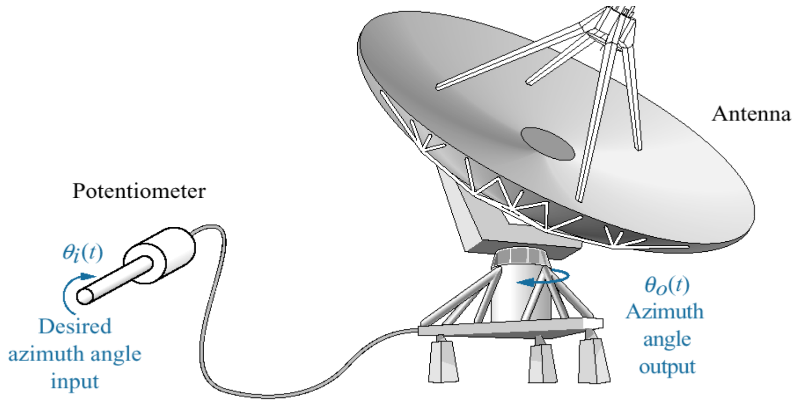
Ex1: Antenna azimuth position control system

a. system concept

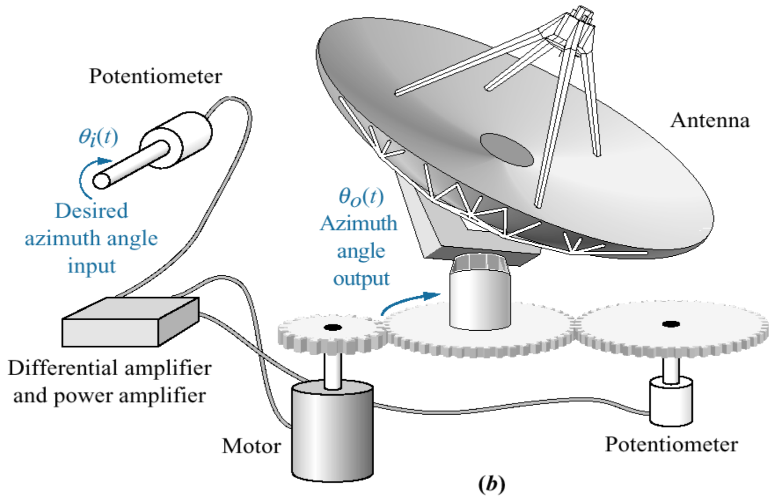
b. detailed layout

The antenna is driven by an electric motor.

The control problem is to command the motor in such a way that the angular position of the antenna tracks the desired angular position.



(a)



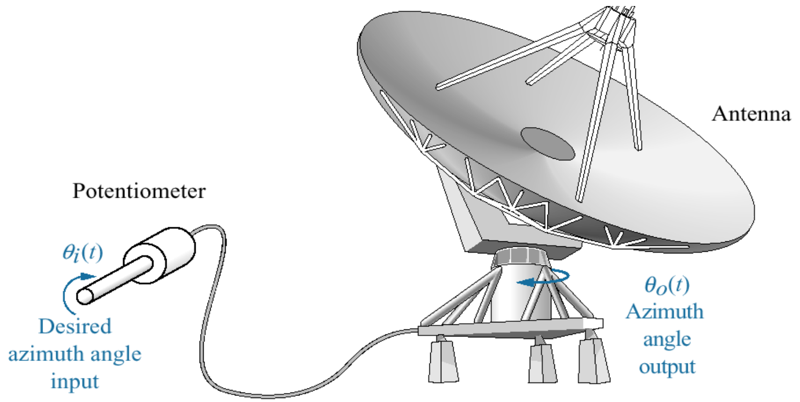
(b)

Ex1: Antenna azimuth position control system

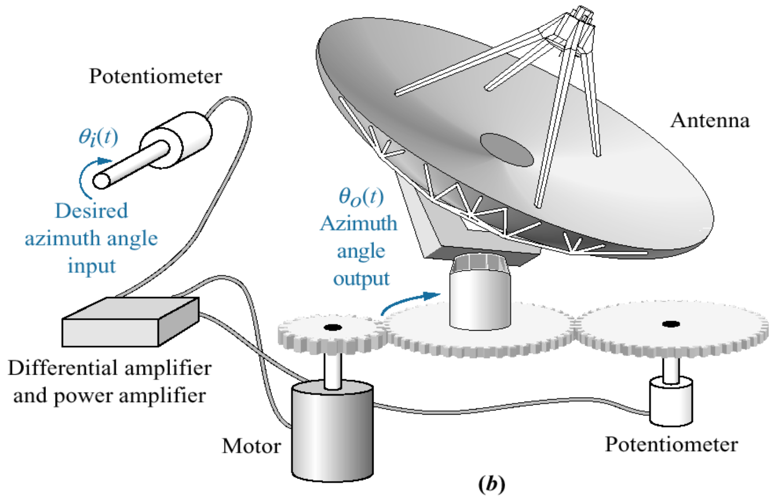
a. system concept

b. detailed layout

The desired angular position is made available as a mechanical angle by manually pointing binoculars in the direction of the desired object.



(a)



(b)

Control Systems Engineering, Fourth Edition by Norman S. Nise

Ex1: Antenna azimuth position control system

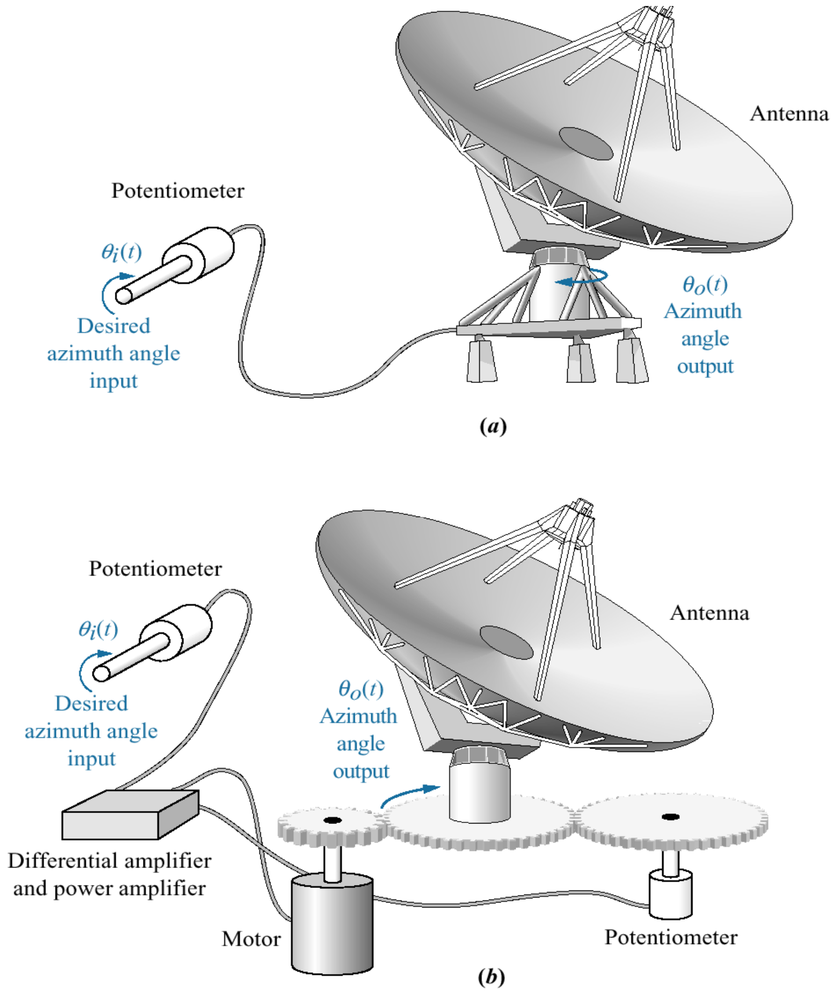
a. system concept

b. detailed layout

The plant consists of the antenna and the motor.

The disturbance is the torque exerted by the wind on the antenna.

The measured variable is the output of a potentiometer mounted on the shaft of the antenna.



Ex1: Antenna azimuth position control system

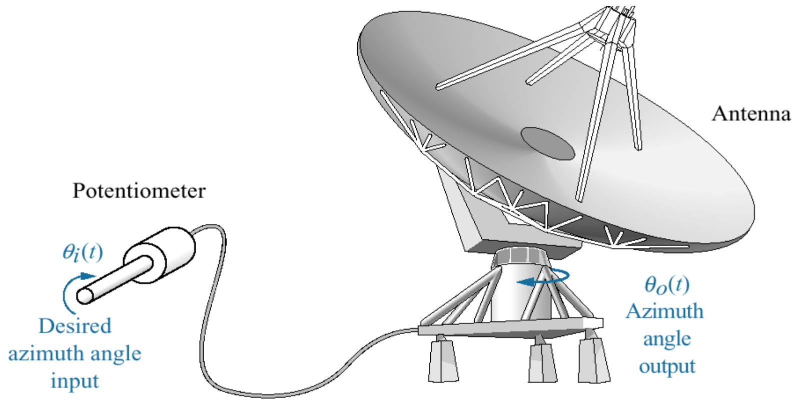
a. system concept

b. detailed layout

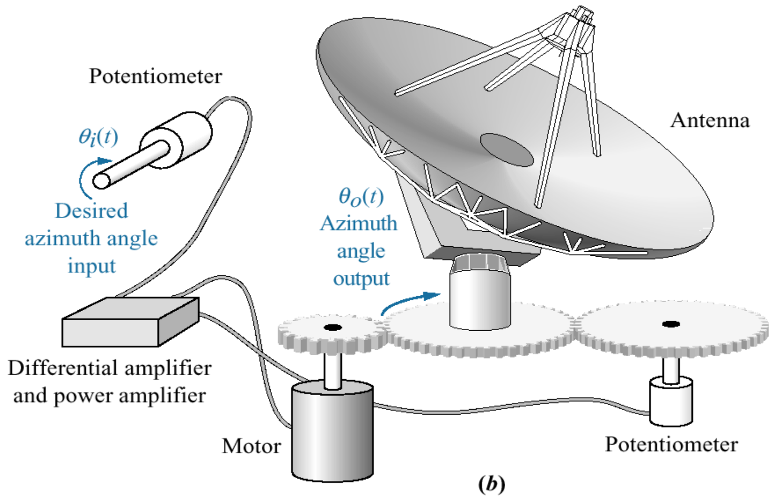
In this example, the azimuth angle of the antenna is the controlled variable.

The reference variable is the direction of the object to be tracked.

The input to the plant is the input voltage to the electric motor.



(*a*)



(*b*)

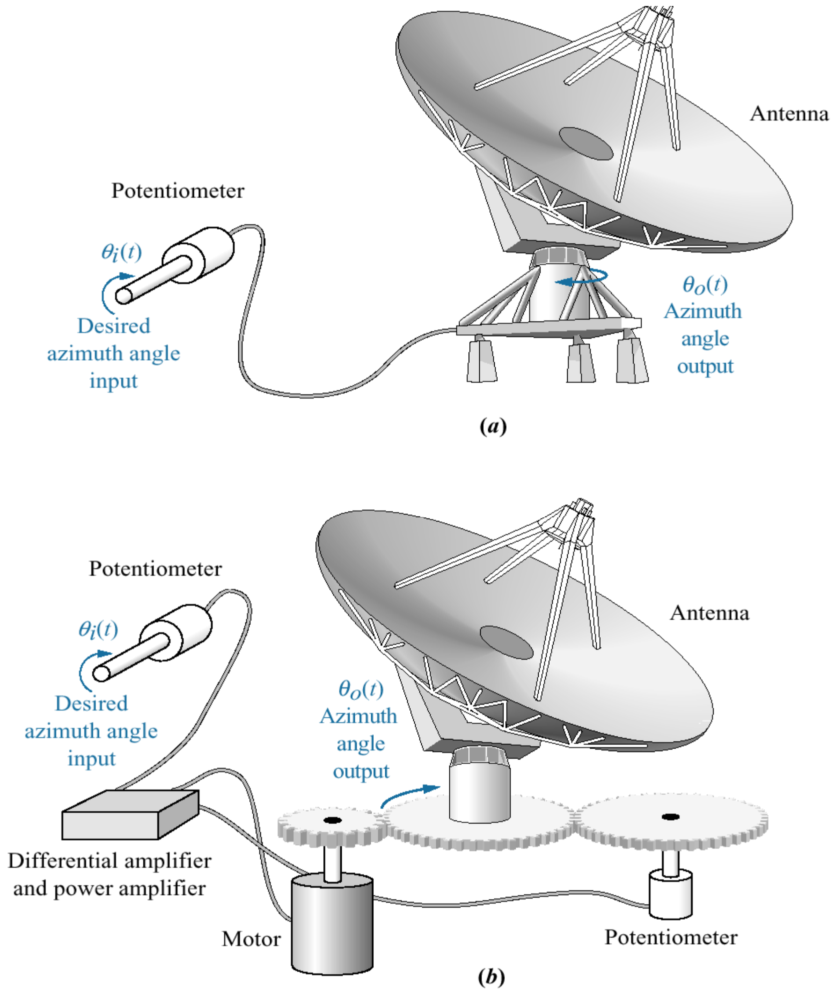
Control Systems Engineering, Fourth Edition by Norman S. Nise

Ex1: Antenna azimuth position control system

a. system concept

b. detailed layout

Both the azimuth angle of the antenna and the angle of the object to be tracked are converted to electrical variables by means of potentiometers mounted on the shaft of the antenna and the binoculars.



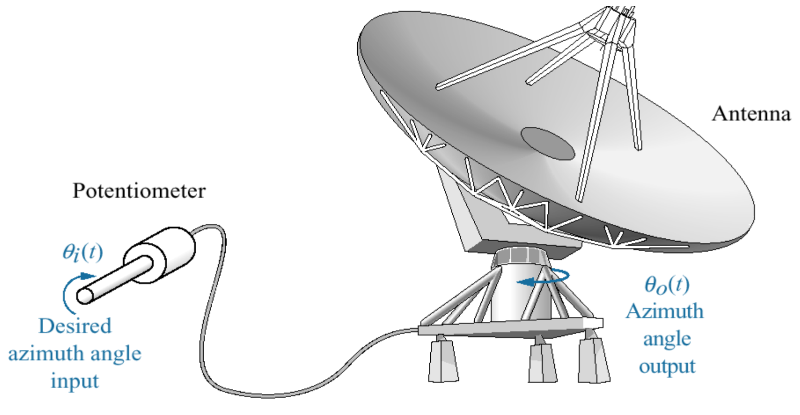
Control Systems Engineering, Fourth Edition by Norman S. Nise

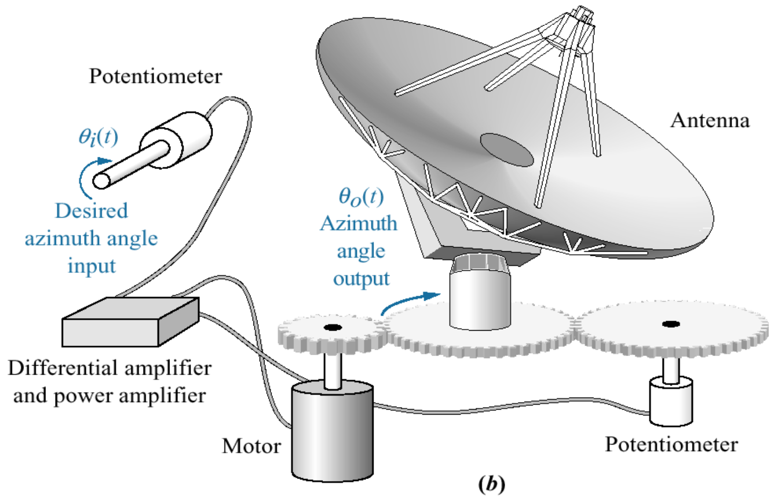
Ex1: Antenna azimuth position control system

a. system concept

b. detailed layout

The output of the difference amplifier is amplified and provides the input voltage to the electric motor.





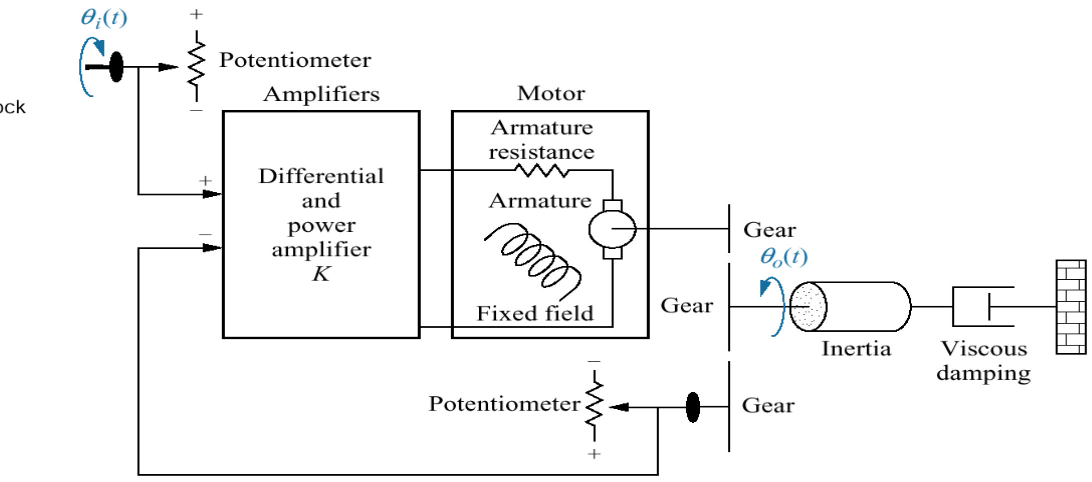
Ex1: Antenna azimuth position control system

c. schematic

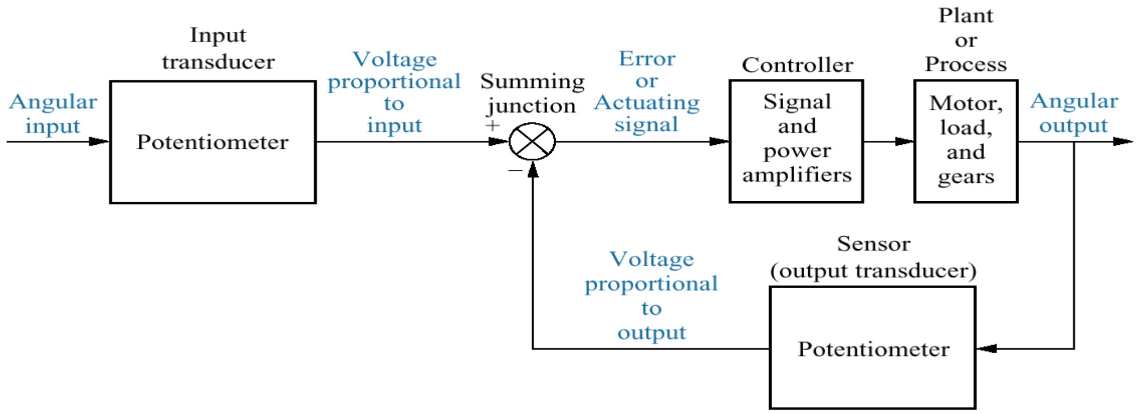
d. functional block diagram

This scheme represents a closed-loop control system.

An open-loop controller would generate the driving voltage on the basis of the reference angle alone.



(c)



(d)

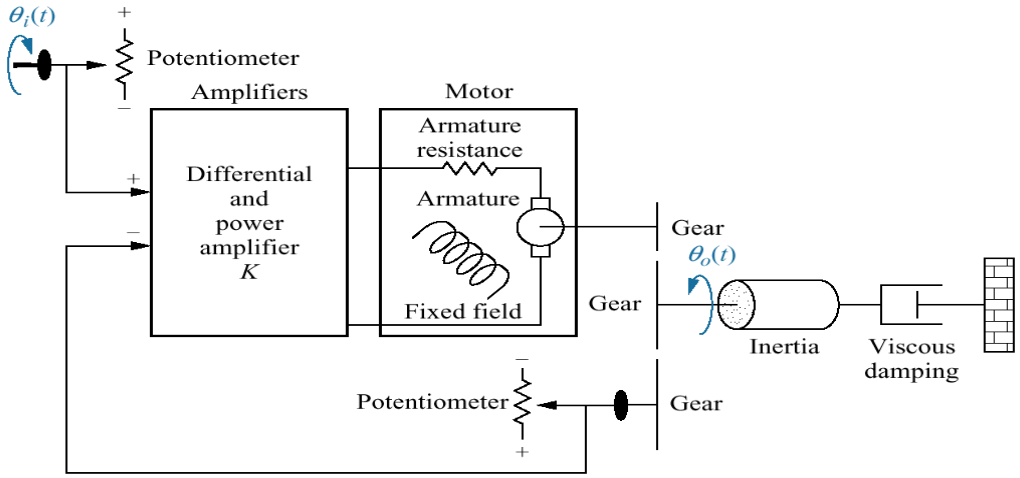
Control Systems Engineering, Fourth Edition by Norman S. Nise

Ex1: Antenna azimuth position control system

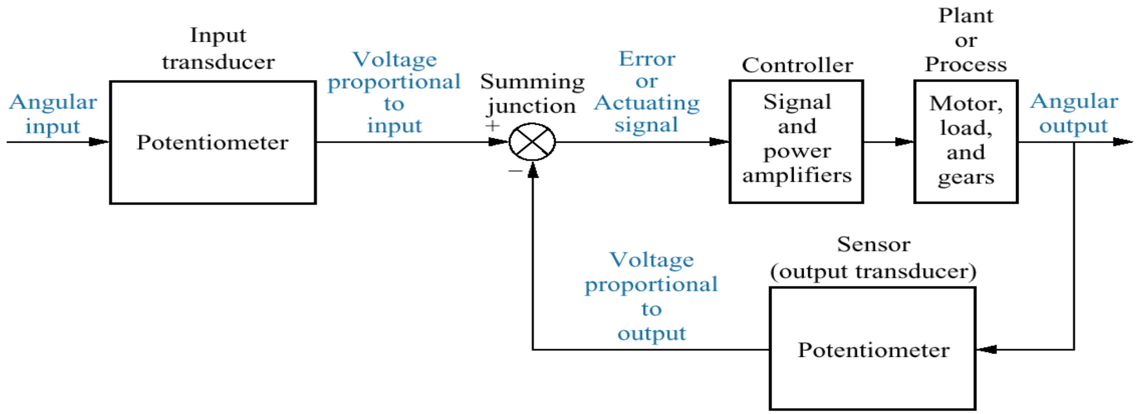
c. schematic

d. functional block diagram

An open-loop controller would not be able to compensate for external disturbance such as wind torques or plant parameters variations such as different friction at different temperatures.



(c)



(d)

Control Systems Engineering, Fourth Edition by Norman S. Nise

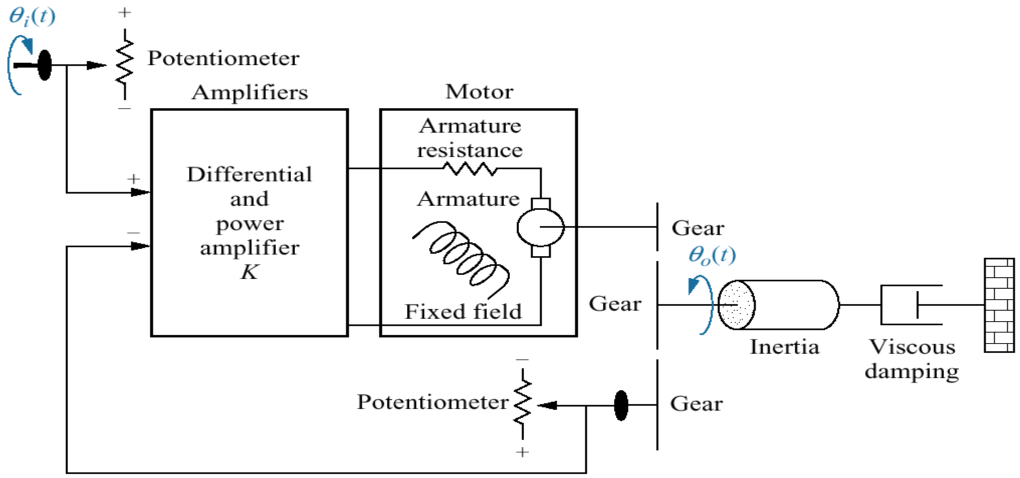
Ex1: Antenna azimuth position control system

c. schematic

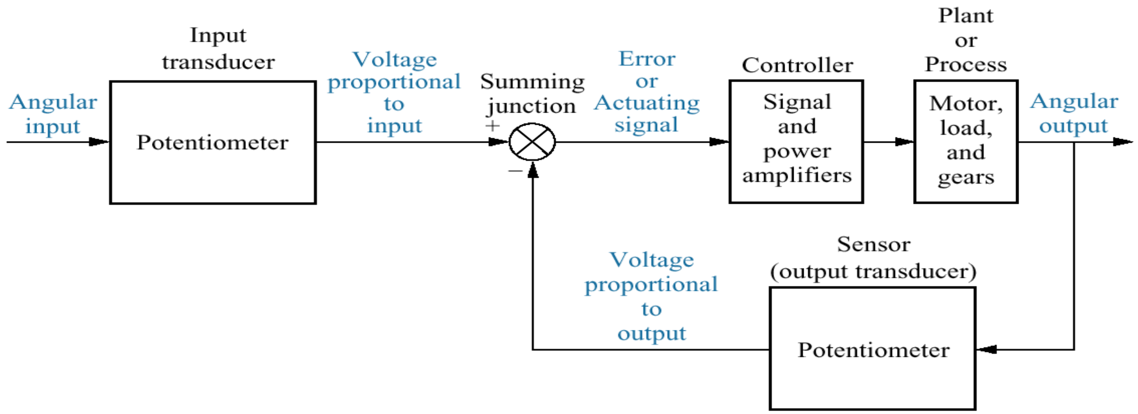
d. functional block diagram

Instead, a closed-loop control system provides actions against external disturbance such as wind torques or plant parameters variations such as different friction at different temperatures.

Control Systems Engineering, Fourth Edition by Norman S. Nise



(c)



(d)

Ex2: Toaster

Analyse:

Controlled variable?

Reference signal?

Disturbances?

Plant?

Plant parameters variations?

Sensors?

Open-loop?

Closed-loop?

Ex3: Watt's flyball governor

Analyse:

Controlled variable?

Reference signal?

Disturbances?

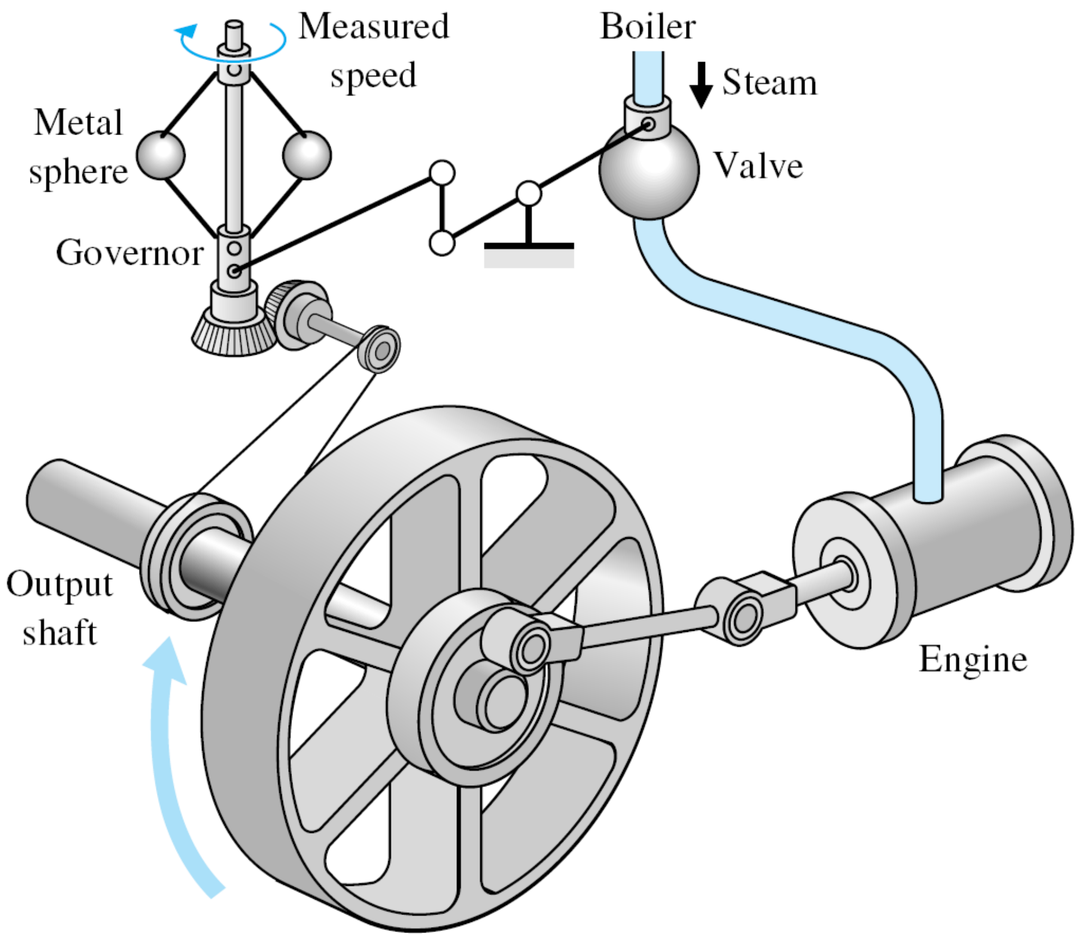
Plant?

Plant parameters variations?

Sensors?

Open-loop?

Closed-loop?



Ex4: Water-level float regulator

Analyse:

Controlled variable?

Reference signal?

Disturbances?

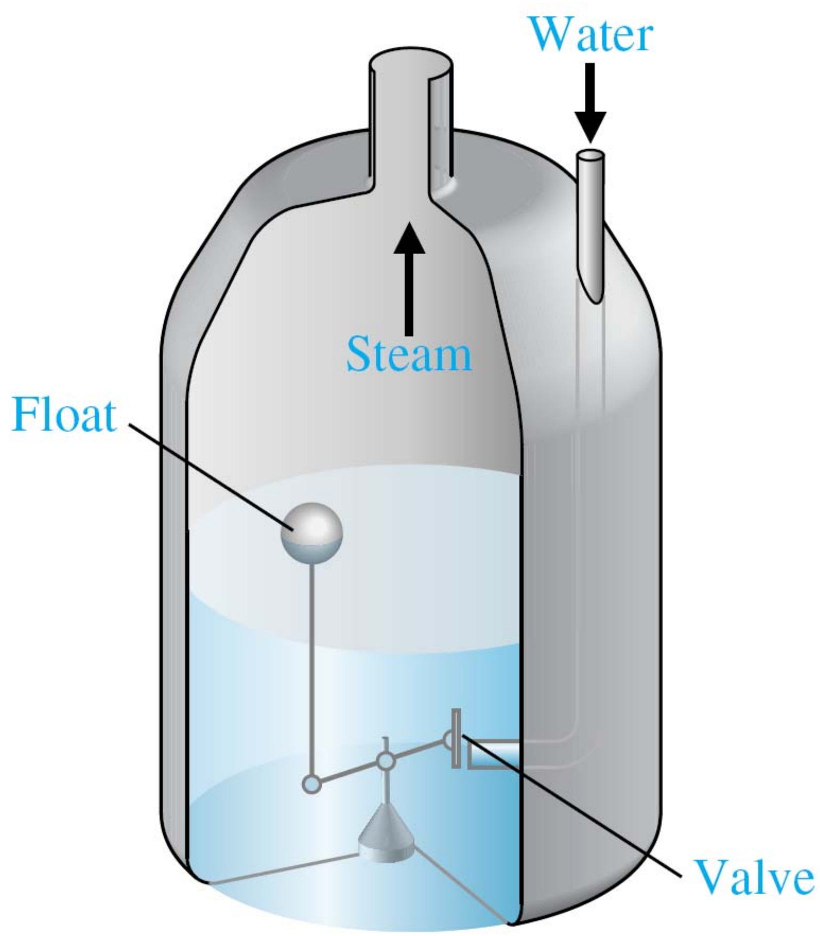
Plant?

Plant parameters variations?

Sensors?

Open-loop?

Closed-loop?

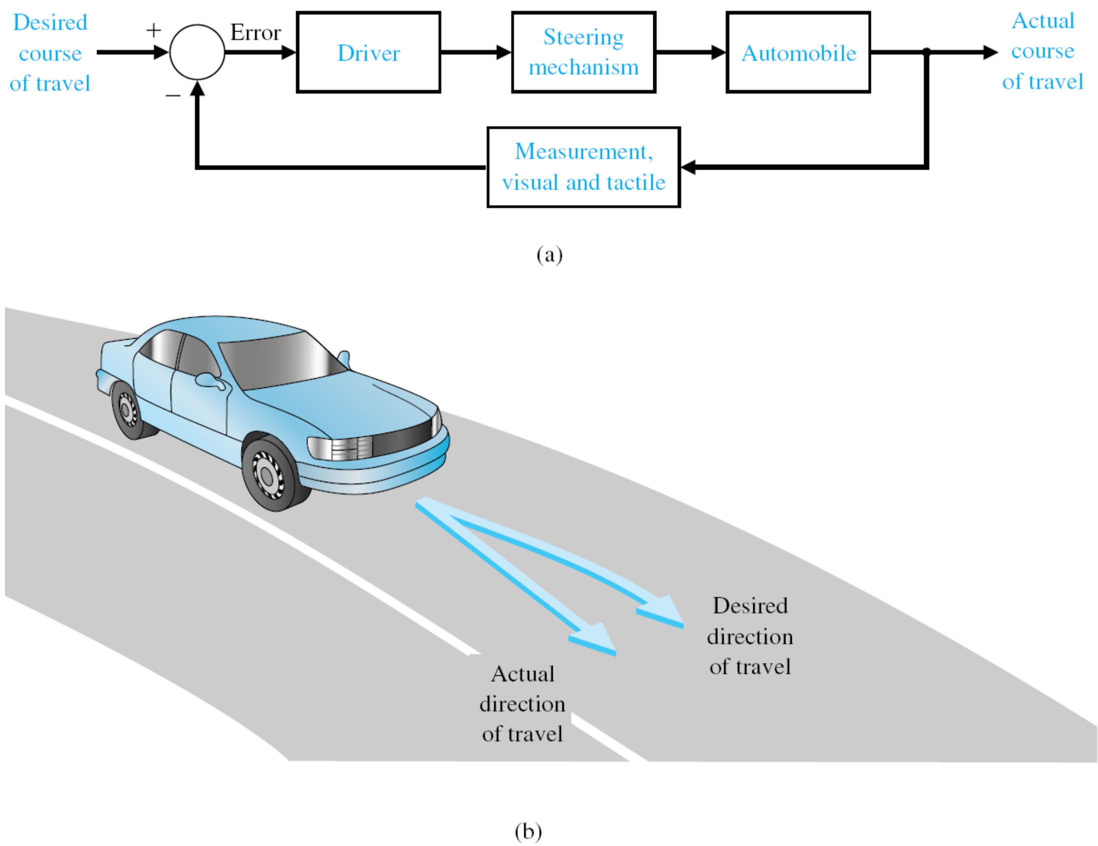


Dorf/Bishop - Modern Control Systems 9/E

Ex5: Automobile steering control system

Analyse:

Controlled variable?
Reference signal?
Disturbances? Plant? Plant parameters variations?
Sensors? Open-loop?
Closed-loop?



(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.

Ex6: Fluid-flow control

Analyse:

Controlled variable?

Reference signal?

Disturbances?

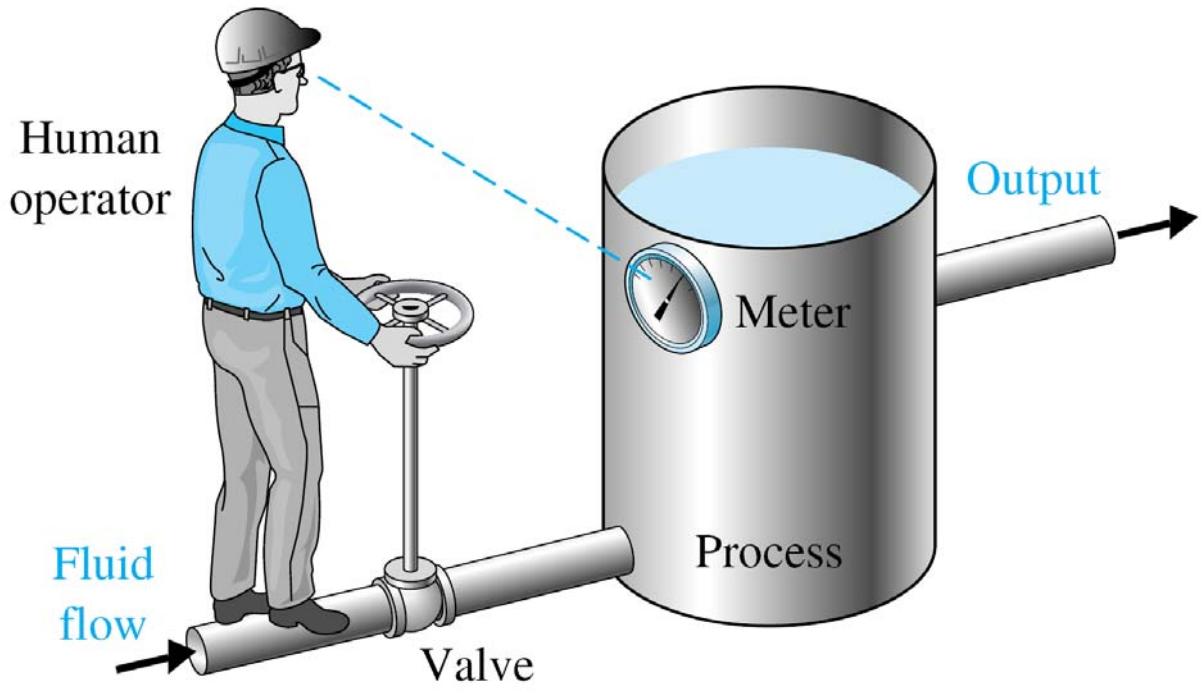
Plant?

Plant parameters variations?

Sensors?

Open-loop?

Closed-loop?



Dorf/Bishop - Modern Control Systems 9/E

Ex6: Water clock

Analyse:

Controlled variable?

Reference signal?

Disturbances?

Plant?

Plant parameters variations?

Sensors?

Open-loop?

Closed-loop?