Automatic Control

Control systems description

Examples of control systems

Course outline

Control systems description

The role of Automatic Control

Automatic Control methods are used whenever some physical quantity, such as a speed, an altitude, a temperature, … must be made to behave in some desirable way over time.

<u>Example</u>: keep constant the speed of a car independently of road slope and wind and maintain the safety distance in the presence of a preceding vehicle → Cruise Control (C.C.)

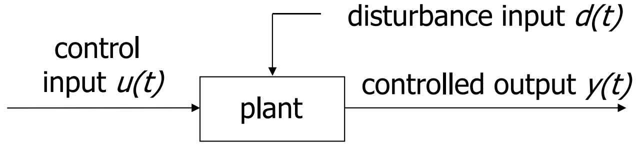
Thus, Automatic Control aims at making the time course of a variable to track some desired behavior (in C.C. to keep constant the car speed) under a variety of operating conditions, automatically (i.e. without human intervention).

A control system is a dynamical system which behaves in a certain prescribed way, in the absence of human action.

Control system description

Basic concepts of a control system

- the **plant**, is the system to be controlled (in C.C., the car)
- the **controlled output** *y(t)*, which is the physical variable under control (in C.C., the car speed and/or the safety distance)
- the **control input** *u(t)*, which influences the plant and is a manipulable variable (in C.C., it is the force needed for accelerating /decelerating the vehicle)
- the **disturbance input** *d(t)*, which influences the plant hindering the achievement of the control purpose and cannot be manipulated (in C.C., it is the force acting on the vehicle provided by the road slope and/or the head wind, the presence of a preceding vehicle)



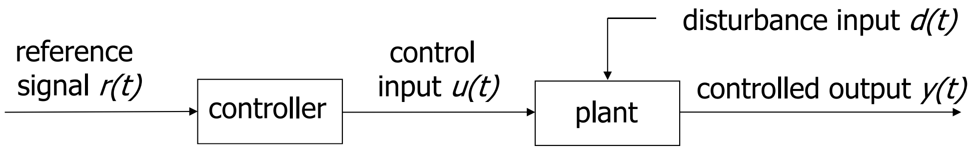
Control system description

▪ the **reference signal** *r(t)* gives the prescribed values of the controlled output (in C.C., the desired value of the car speed)

▪ The control input to the plant is provided by a device which is referred to as **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.



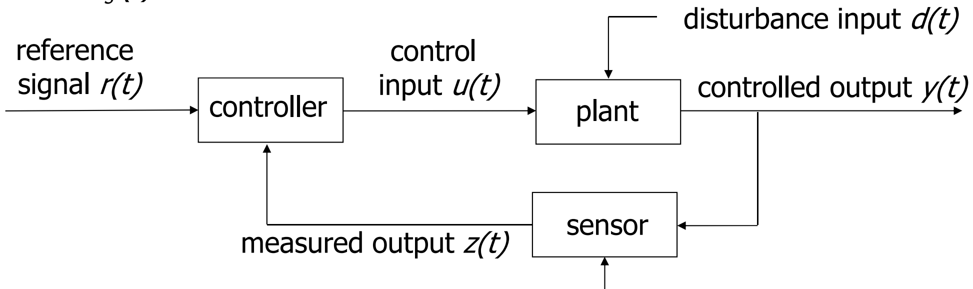
* also referred to as "feedforward controllers"

Control system description

Closed-loop controllers* exploit the information about the plant through

▪ the feedback of the **measured output** *z(t)*, which is obtained by means of one of more **sensors**

▪ a **sensor** is a device that **measures a physical quantity** and converts it into an electrical signal which can be read by a suitable instrumentation (in C.C., tachometer and radar). The measured output is affected by the **sensor noise** $d_s(t)$

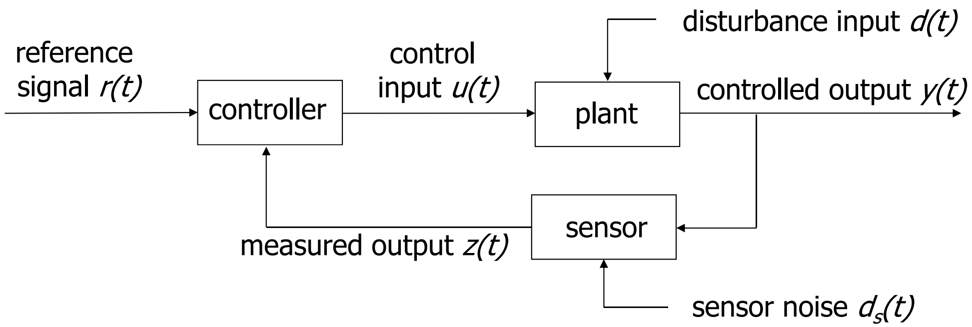


* also referred to as "feedback controllers"

Control system description

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

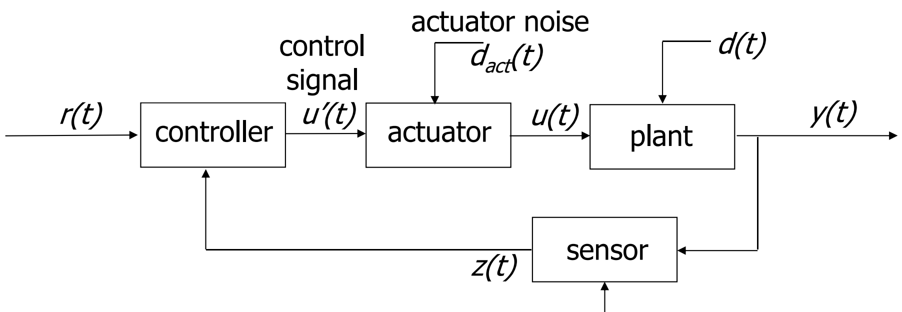
▪ Closed-loop control is more powerful than open-loop control since it is able to reduce the effects of the disturbances and compensate for plant parameters uncertainty and variations.



Control system description

▪ Basically, the controller is an analog/digital electronic device which provides a low power **control signal** *u′(t)* (an electric quantity) not able to produce the needed control action to the plant.

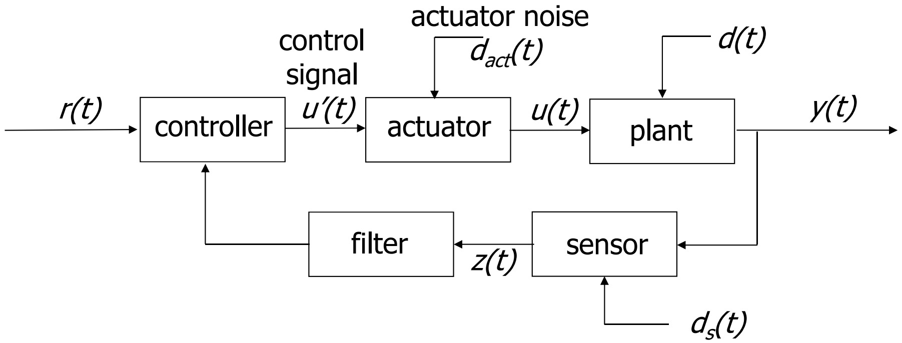
▪ An **actuator*** is tipically introduced in order to convert the control action of the control signal in the required action on the plant with the needed power properties (in C.C., the engine/braking system)



* e.g. electric motors, pumps, …

Control system description

- The **reference signal** $r(t)$ is realized through an electric signal
- A low pass **filter** is tipically introduced downstream the sensor in order to make comparable the sensor output and the reference signal and to reduce the effects of the sensor noise.



Examples of control systems

Application area of Automatic Control

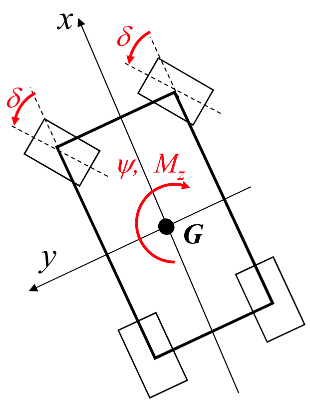
- Aeronautics & aerospace
- Automotive
- Biomedical
- Computing systems
- Energy
- Networks
- Process control
  chemical,
  pharmaceutical,
  steel, ...
- Robotics
- Telecommunications
- Transportation
- … many others

Example 1: Vehicle active stability control

Objectives of vehicle active stability control systems:

- Improve comfort/handling performance due to understeer behavior (e.g. steady state cornering at high speed)
- Assist the driver in critical driving conditions (e.g. sudden lane change)
- Keep directionality in the presence of external disturbances (e.g. a blast of wind) and during demanding maneuvers (e.g. braking on wet asphalt)

Example 1: Vehicle active stability control



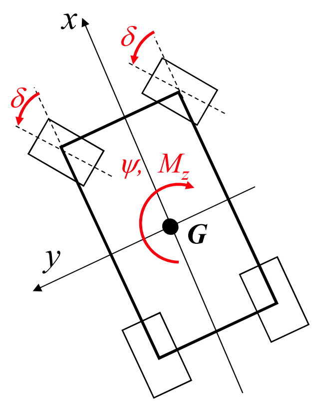
The directional vehicle behavior is well described by the **yaw rate** variable $\dot{\psi}(t)$ which is assumed as the **controlled output** y(t)

Vehicle passive behavior can be modified through an external **yaw moment** M_z generated by means of a suitable device, thus M_z is assumed as the **control input** u(t)

The **steering angle** δ provided by the human driver is seen as a **disturbance** as well as varying friction characteristics of the road and the presence of lateral wind

The yaw rate **reference** course $\dot{\psi}_{ref}(t)$ is computed on the basis of the maneuvering conditions and depends on δ and *v* (vehicle speed)

Example 1: Vehicle active stability control



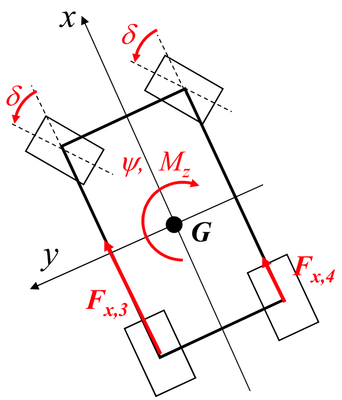
The yaw rate is measured by means of a **gyroscope** which makes up the **sensor** used for the feedback of the controlled output

An **Electronic Control Unit** (ECU) is the digital device, i.e. the **controller**, usually employed in the automotive field, which provides the control action u'(t) in the form of a voltage/current (v(t) / i(t)) to drive the actuator

Several **actuators** can be employed to realize the yaw moment action required by the controller. Some examples are:

- active differential (RAD, …)
- active steering (AFS,…)
- braking forces (VDC, ESP)

Example 1: Vehicle active stability control

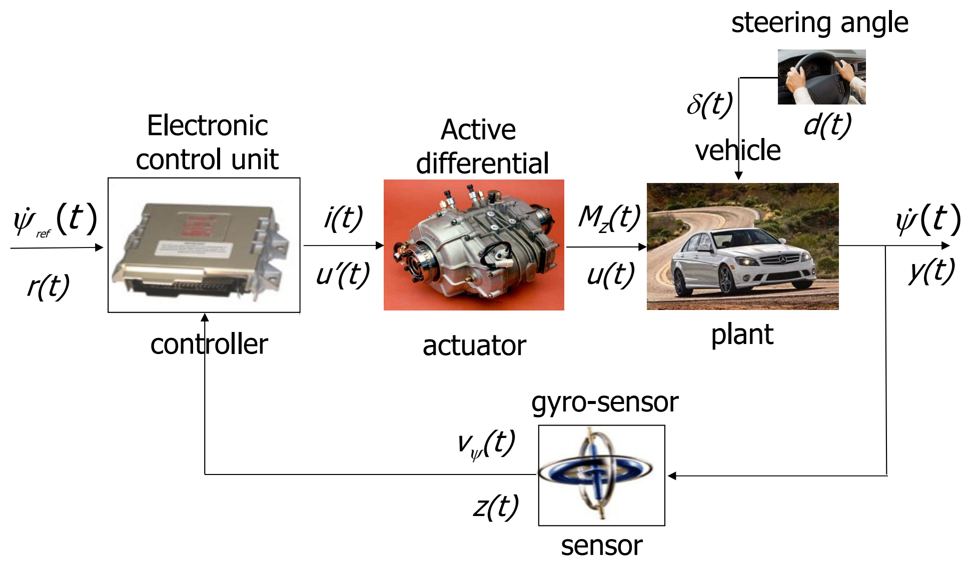


As an example, a (rear) active differential is able to generate longitudinal forces of every direction and entity (within the device physical limitations)

$$M_z \simeq F_{x,3}y_3 + F_{x,4}y_4$$

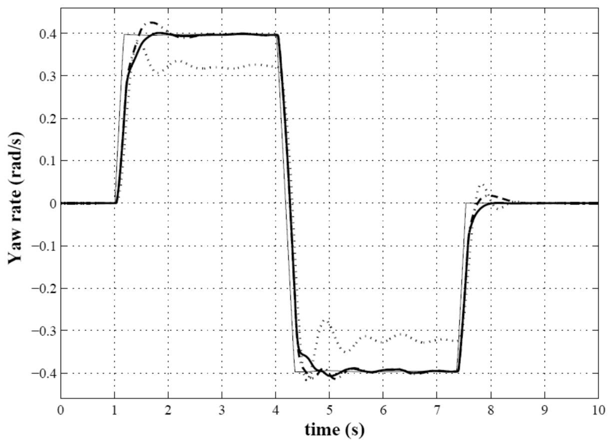
$$y_3, y_4 \;\rightarrow\; \text{arms of } F_{x,3}, F_{x,4}$$

Example 1: Vehicle active stability control



Example 1: Vehicle active stability control

Steer reversal maneuver @ 80 km/h



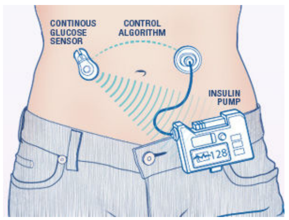
Example 2: Insulin delivery control in type 1 diabetics

- The pancreas is an organ in the body that secretes several hormones, including insulin and glucagon. Insulin helps cells in the body take up glucose (sugar) from the blood to use for energy, which lowers blood glucose levels. Glucagon causes the liver to release stored glucose, which raises blood glucose levels.
- Type 1 diabetes occurs when the pancreas produces little or none of the insulin needed to regulate blood glucose.
- To obtain tight control of their blood glucose levels, individuals with type 1 diabetes must monitor their blood glucose concentration through frequent fingerstick measurements, and give themselves insulin shots.
- It is easy to understand that this well established medical protocol may cause limitations in the social life of diabetics.

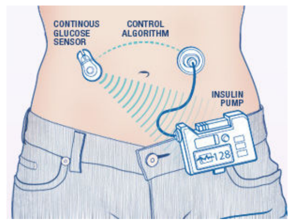
Example 2: Insulin delivery control in type 1 diabetics

- Ongoing researches made in strict connection by physicians and ICT engineers aim at developing an artificial pancreas, consisting of:
  - a glucose sensor
  - an insulin infusion pump
  - a computer-controlled algorithm which connects the glucose sensor and insulin infusion pump to allow continuous communication between the two devices and provide for insulin delivery when needed

An artificial pancreas device system is thus referred to as a "closed-loop" system or an "autonomous system for glycemic control."



Example 2: Insulin delivery control in type 1 diabetics



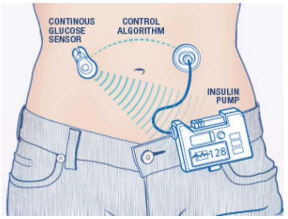
The variable of interest, i.e. the **controlled output** y(t), is the **blood glucose concentration** G(t) [mg/dl], → normoglycemic range 60-120 mg/dl

The **insulin infusion rate** I(t) [mU/min] is the **control input** u(t) → range 0-100 mU/min

The **meal glucose intake** M(t) [g] → range 50-100 g, is the **disturbance**. It is usually transformed in the **glucose absorption rate** [mg/min] → about 300-600

The **reference** signal r(t) corresponds to the **euglycemic glucose level** $G_{ref}(t)$ [mg/dl] → typically 80-90 mg/dl

Example 2: Insulin delivery control in type 1 diabetics

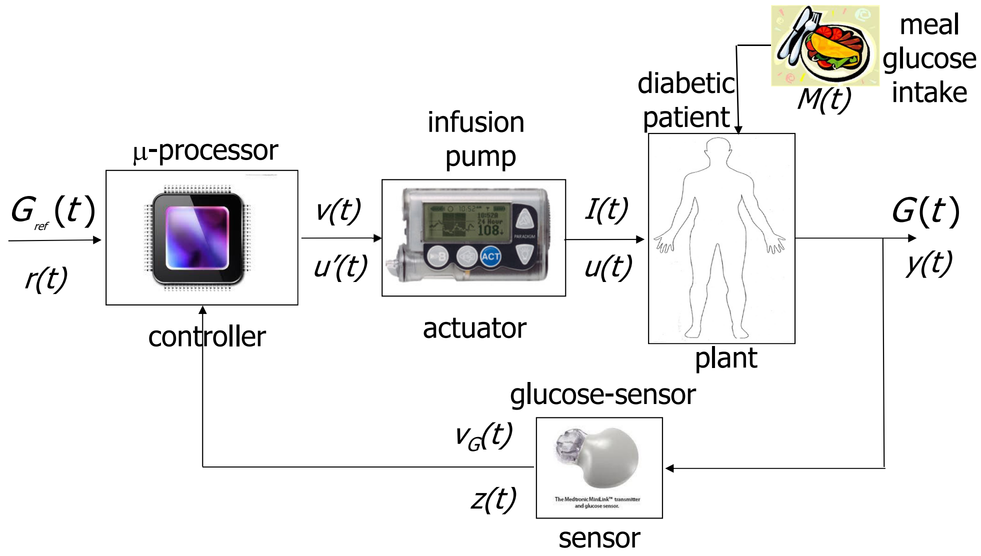


The blood glucose concentration can be derived through the measurements of a **transdermic sensor** which is the **sensor** used for feeding back the controlled output. The sensor output voltage $v_G(t)$ is transmitted to the controller via a wireless technology

A **processor** embedded in the pump is the **controller**, which provides the control action u′(t) in the form of the driving voltage v(t) of the pump

The **actuator** is the **infusion pump** that provides the required insulin infusion rate

Example 2: Insulin delivery control in type 1 diabetics



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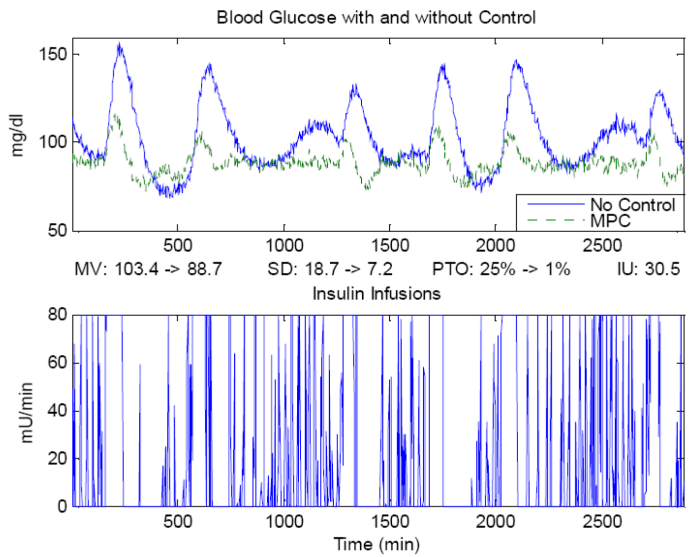

Course outline

Major topics 1/3

- State space and transfer function descriptions of dynamical systems

→ to get a plant mathematical model needed either to analyse its behavior or to perform the design of a control system

- Solution of state equations, modal analysis

→ to analyze the dynamic behavior of a plant and evaluate, according to the following point, if it has to be modified through the design of a control system

- Stability of linear systems
- Time response of first and second order systems

→ to define appropriate behaviors of dynamical systems as requirements for the design of a control system

Major topics 2/3

- Bode, polar, Nyquist and Nichols diagrams

→ to introduce suitable tools for the analysis and the design of a control system

- Feedback control structures

→ to define the principle of feedback in the control of dynamical systems

- Internal stability of feedback systems, Nyquist stability criterion

→ to analyze stability properties of feedback control structures

- Feedback systems steady state and transient response analysis

→ to define steady state and transient requirements of a control system

Major topics 3/3

- Control design by means of sinusoidal tools using lead, lag and PID functions.

→ to introduce basic control design techniques through the use of analog filters

<u>For INF only:</u>

- Analysis and design of sampled data control systems

→ to obtain a controller through a digital filter

- Lab. Activities on digital control implementation
- Short accounts on:

nonlinear systems → to motivate use of linear systems

control system design using state space representation → to show another design approach