Control Systems and Adaptive Process. Design, and control methods and strategies

1. Open-loop and closed-loop systems

The concepts of open-loop or closed-loop are linked to control systems with or without feedback.

As discussed in previous modules, there are clear advantages of feedback systems. Most systems use electronic control circuits in closed loop. However, it is sometimes interesting regulation by open loop, in fact, a large number of electronic systems can work in both modes.

When an electronic system is manufactured is more or less easy to proceed to its factory calibration, where they have all the necessary tools, however, to calibrate equipment already installed at its final location, without the availability of the equipment used during production, can become a difficult task. Therefore it is appropriate that electronic systems implement the possibility of control merely depending on inputs, without the influence of the output, enabling to take them to a certain state in a controlled manner. To understand this concept, consider an uninterrupted power supply that in normal situation, is constructed to provide a stable voltage at its output regardless of load variations, line voltage variations, etc.., i.e., by a closed-loop control. If this equipment breaks and needs to be calibrated, it must be isolated from all these external factors affecting its regulation, otherwise it would be impossible to make an accurate adjustment. It seems logical that such systems permit the possibility to work in a way that inhibits all external signals and allows achieving output values as commanded by the technician who is calibrating. That is, that it can function in open-loop. In the same way it would happen with any system.

1.1 Open-loop systems

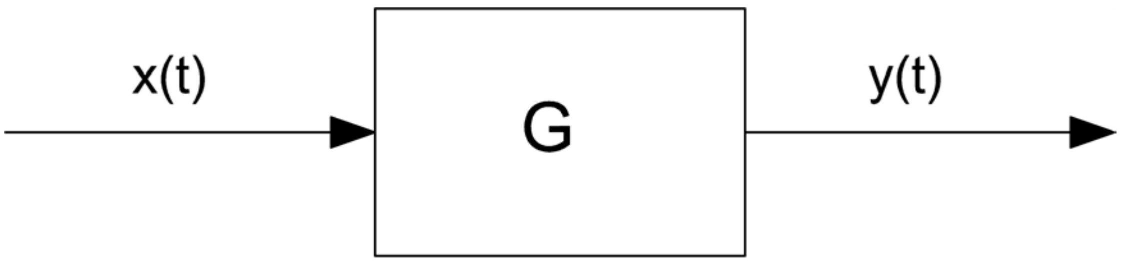
Open-loop systems are those in which the action parameters of the system do not depend on the output variable or variables, but exclusively on the input variables. As an example we might consider a heating system in which the boiler will work controlled by a timer that will mark the intervals of connection or disconnection. As you can see the operation of such systems is determined by the criteria and estimation of the designer, in this case, the person who sets this timer, and not by the results of the output based on the variables affecting the system (ambient room temperature, outside temperature, the opening or closing of doors and windows).

With this example it is clear that this type of system does not adapt to external conditions or perturbations. Thus, the accuracy of an open loop system largely depends on its calibration.

It is logical to think that such control systems are only suitable for some specific situations:

- When operating conditions are well defined, are very stable and the control variables are little influenced by external factors.
- When variables under control are allowed to significantly vary on desired values or their dynamics is not very relevant because the regulation to be performed is very slow.
- When the system operates on discrete values that produce jumps in the output variable under control, so that a control in closed-loop could lead to instabilities because of an "excess" of control.
- In bang-bang control systems.
- In low-cost systems.

An open chain system may be represented by the following diagram, which shows that the output signal depends only on the input and the transfer function *G(s)* of the system.



Expressed in the domain of *s*, we could say that

$$\frac{Y(s)}{X(s)} = G(s)$$

Las The advantages of the control systems in open-loop are:

- Simple and stable.
- Reduced cost.
- Easier to build.

Its disadvantages are:

- Less precision or accuracy.
- Less reliable.
- Due to the lack of feedback or knowledge of the output, can not eliminate their own or external perturbations.

Remember that, as seen in previous modules, the study of some aspects of the systems with closed-loop or feedback is based on prior knowledge of the behavior of systems in open-loop.

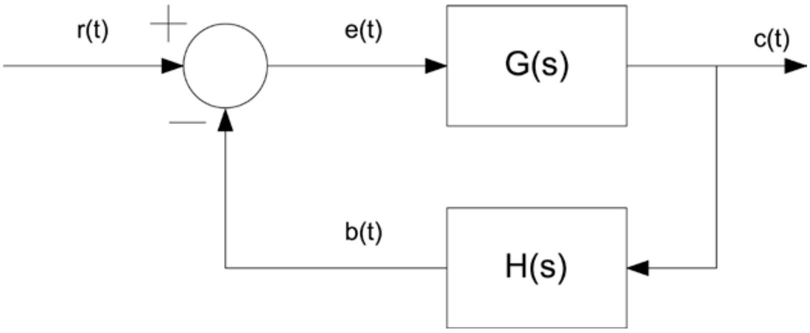
In short, the use or not of control systems in open-loop depends on the application to control, especially on how critical the process output is.

1.2 Closed-loop systems

A closed-loop system is one in which the output has an effect on the control signal, and therefore the actuating error signal (which is the difference between the input and the feedback signals) that enters the controller to reduce error and lead the output to the desired value. The feedback signal may be equal to the output or to a function of its derivatives (proportional, integral, derivative, a combination of them, etc.).

In this type of system the parameters are set primarily according to the value of the output variable to regulate.

A scheme of this type of control can be observed in the following figure, which shows a transfer function *G(s)* on which acts the signal error e *e(t)*, and a feedback function *H(s)* which is function of the output *c(t)*. The error signal is the difference between the reference signal and the feedback signal.



Expressed in the domain of *s*, we have

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)H(s)}$$

In the case of unitary feedback, the output will be:

$$C(s) = G(s)E(s) = G(s)\left[R(s) - C(s)\right]$$

or what is the same:

$$C(s) = \frac{G(s)}{1+G(s)}R(s)$$

In the case of unitary feedback error would be:

$$E(s) = \frac{1}{1+G(s)}R(s)$$

i.e., to reduce the error, the value of [1+*G(s)*] should be greater than 1 in the considered interval of *s*.

Assuming that *H(s)*≠1, the output signal will be

$$C(s) = G(s)E(s) = G(s)\left[R(s) - H(s)C(s)\right]$$

and therefore

$$C(s) = \frac{G(s)}{1+G(s)H(s)}R(s)$$

The error signal in this case is

$$E(s) = \frac{1}{1+G(s)H(s)}R(s)$$

i.e., to reduce the error, the value of [1+*G(s)H(s)*] should be much greater than 1 in the considered interval of *s*.

A closed-loop system (or feedback loop) provides more precise control than other open-loop, however, it can become unstable if it is not well designed. For example, if the gain is too high, it may occur on the system an over-correction of error that may cause an increasing output oscillation. A system that is unstable is uncontrollable and, therefore, completely useless.

From this point of view, the problem of stability occurs when designing such systems, leading to increased complexity in the system design than in open-loop systems.

Advantages of control systems in closed loop:

- Accuracy: the knowledge of the output, i.e., the result of his performance, allows to correct the error and achieve high accuracy.
- Allows to eliminate internal and external perturbations.

Disadvantages of this kind of systems:

- More complex construction and design.
- Higher cost than in open-loop systems.
- Due to the feedback oscillatory responses may occur.
- Instability: since the output affects the control, in certain circumstances instability may appear. In fact this may be the most important problem at the time of design.

The use of feedback involves the addition of (at least) a sensor to the system capable of detecting the output variables and, in general, of a transducer that "translates" the measured in a language understandable by the controller. For example, in a speed control system utilizing a sensor capable of measuring the revolutions of the wheel is essential, and a system that converts the number of turns in kilometers per hour or a control signal that is equivalent to that speed.

Sensors become one of the key components of the system, which can introduce errors, noise, etc.

Another problem of feedback is gain loss. While in open-loop system gain was determined by $G(s)$, the same system in single closed loop will have a gain equivalent to $[G(s)/(1+G(s))]$. Gain is therefore reduced by a factor $[1/(1+G(s))]$, which coincides with the factor in which the system sensitivity against perturbations and variations in the parameters reduces.

As mentioned in the introduction, most closed-loop control systems include open-loop control possibility, even if only for very specific occasions of maintenance, calibration, etc.

In some systems the possible stability problems are solved using regulations with different characteristics in certain parts of the process to be controlled. In the above example of uninterruptible power supplies, the output signal generated in the inverter must have a high dynamic response, in order to satisfy the conditions of power to the load against possible variations of it, however, a similarly high dynamic response at the input of the inverter, may be the cause of the occurrence of oscillations or instabilities, so normally the rectifier usually has a slower regulation.

In conclusion, closed-loop control systems have a more accurate control than open-loop, although are more expensive and complex to design. Nowadays, most of the processes are controlled by closed loop, even in very simple systems, as the additional cost compensates the improvements it introduces.

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