Course : CSE461

Class Note : Introduction to Control Theory

Cybernetics:

In robotics, cybernetics deals with the study of how feedback and control systems can be used to guide and direct robotic systems. This area of research covers a wide range of topics, from the design of simple feedback loops to the development of more complex control architectures.

Control Theory:

Control theory provides a systematic approach to the analysis and design of control systems. It allows engineers and scientists to predict the response of a system to a given input and to assess the stability of the system. By understanding how a system will behave under different conditions, it is possible to design controllers that can manipulate the inputs to the system in order to achieve a desired output. This can be useful in a wide range of applications, from regulating the temperature in a building to controlling the movement of a robotic arm.

Open-loop control:

An open-loop control system is a type of control system in which the output is not fed back to the input for correction. In other words, the system does not use feedback to determine if the output has achieved the desired goal. Instead, the system operates based on a predetermined sequence of actions or a fixed set of rules.

An example of an open-loop control system is a washing machine. The user selects the desired wash cycle and the machine operates based on a predetermined sequence of actions (filling with water, agitating, draining, spinning, etc.) without any feedback on whether the clothes are actually clean.

Open-loop control systems are generally simpler and less expensive than closed-loop control systems but they can be less accurate and less able to adapt to changing conditions.

Closed loop systems:

A closed-loop control system is a type of control system in which the output is fed back to the input for correction. This feedback allows the system to adjust its actions based on the difference between the desired output and the actual output. The goal of a closed-loop control system is to minimize the error between the desired and actual outputs.

An example of a closed-loop control system is a thermostat. The thermostat measures the temperature in a room and compares it to the desired temperature. If the room is too cold, the thermostat sends a signal to turn on the heating system. As the room warms up, the thermostat continues to measure the temperature and adjust the heating system until the desired temperature is reached.

Closed-loop control systems are generally more accurate and more able to adapt to changing conditions than open-loop control systems but they can be more complex and more expensive.

Characteristics of Feedback Control System:

A feedback system is a type of control system that uses feedback to adjust its actions based on the difference between the desired output and the actual output. Some characteristics of a feedback system include:

Power amplification: A feedback system can use a small amount of power to control a large amount of power. For example, a small electrical signal can be used to control a large motor.

Actuator: An actuator is a component of a feedback system that converts the control signal into an action. For example, a motor is an actuator that converts an electrical signal into mechanical motion.

Feedback: Feedback is the process of measuring the output of a system and comparing it to the desired output. The difference between the desired and actual outputs is used to adjust the system's actions.

Error signal: The error signal is the difference between the desired and actual outputs. It represents the amount by which the system needs to be adjusted in order to achieve the desired output.

Controller: The controller is the component of a feedback system that processes the error signal and generates a control signal to adjust the system's actions.

Goal of a control system:

The goal of a control system is to achieve a desired output by manipulating the inputs to a system. Some common goals of control systems include:

Regulation: Regulation is the process of maintaining a system's output at a constant value or within a desired range. For example, a thermostat regulates the temperature in a room by turning the heating or cooling system on and off as needed.

Tracking: Tracking is the process of making a system's output follow a desired reference signal. For example, a cruise control system tracks the desired speed of a car by adjusting the throttle.

Optimization: Optimization is the process of finding the best possible solution to a problem. In control systems, optimization can involve finding the best set of inputs to achieve a desired output while minimizing costs or maximizing performance.

Why do we need the conversion of signal from time domain to frequency domain?

One technical reason for converting a time-domain signal to a frequency-domain signal is that it can simplify the analysis of signals and systems. Many mathematical operations that are difficult to perform in the time domain become much simpler in the frequency domain. For example, convolution in the time domain becomes multiplication in the frequency domain. This can make it easier to analyze how a system will respond to different inputs.

Another technical reason is that many systems and devices respond differently to different frequencies. By converting a time-domain signal to a frequency-domain signal, you can see how the system or device will respond to each frequency component of the input signal. This can make it easier to design filters or other systems that manipulate the frequency content of a signal.

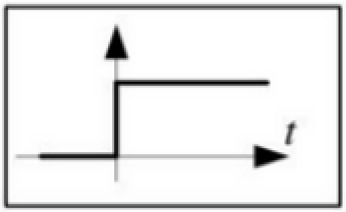
Transfer Function:

The transfer function is a mathematical representation of the relationship between the input and output of a system. It provides information about how the system will respond to different inputs. By analyzing the transfer function, you can determine the behavior of the system in both the time and frequency domains.

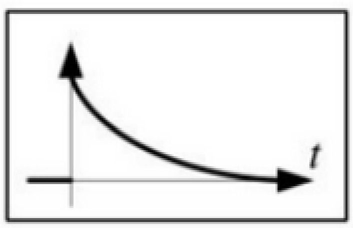
$$H(s) = Y(s) / X(s)$$

The transfer function can be used to determine the stability of a system, its steady-state response to different inputs, and its transient response to changes in the input. It can also be used to design controllers to achieve desired performance.

Steady-State:
In the context of a control system, the steady-state response refers to the behavior of the system after it has settled and reached a stable operating point. This is the long-term behavior of the system after any initial transients have died out.



Transient State:
The transient response, on the other hand, refers to the behavior of the system during the initial period after a change in the input or a disturbance. This is the short-term behavior of the system as it responds to changes and moves towards its new steady-state operating point.

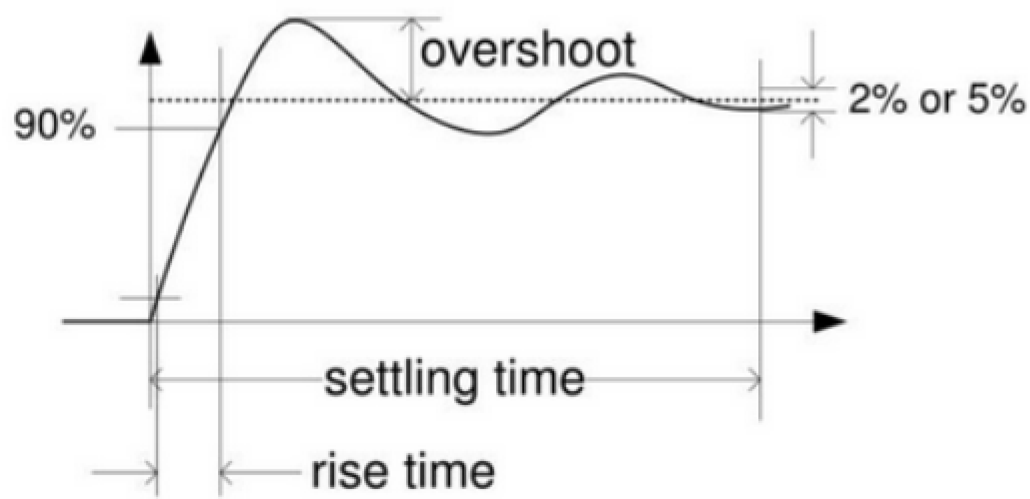


Overshoot and Undershoot: overshoot refers to the amount by which the system's output exceeds its final steady-state value in response to a change in the input or a disturbance. Undershoot is the opposite of overshoot and refers to the amount by which the system's output falls below its final steady-state value.

Overshoot = | actual value - steady state value |

% of overshoot = (| actual value - steady state value | / steady state Value) x 100 %

Rise time: It is the time it takes for the system's output to rise from a specified low value to a specified high value in response to a change in the input or a disturbance. It is typically measured as the time it takes for the output to rise from 10% to 90% of its final steady-state value.



Settling time: Settling time is the time it takes for the system's output to settle within a specified tolerance band around its final steady-state value after a change in the input or a disturbance. It is typically measured as the time it takes for the output to remain within a specified percentage (usually 2% or 5%) of its final steady-state value.

Control Algorithms:

Proportional Control:

A proportional controller is a type of feedback controller that calculates the control action as a proportion of the error signal. The error signal is the difference between the desired setpoint and the measured process variable. The control action is calculated by multiplying the error signal by a constant gain factor. This means that the control action is directly proportional to the error signal.

$$u(t) = K_p e(t)$$

Here e(t) is the error signal and u(t) is the output signal of the controller.

Proportional controllers are simple to implement and can provide good performance for many systems. However, they can also suffer from steady-state error and may not be able to completely eliminate the error between the setpoint and the process variable.

too high of a proportional gain can lead to instability and oscillations in the system's response.

Integral Control:

Integral control is a type of feedback control that calculates the control action based on the accumulated error over time. The error signal is the difference between the desired setpoint and the measured process variable. The integral controller calculates the control action by multiplying the integral of the error signal by a constant gain factor.

$$u(t) = K_i \int_0^t e(t)dt$$

The integral action accumulates the error over time and produces a control action that is proportional to the accumulated error. This means that even small errors will eventually result in a large control action if they persist for a long time. This can help to eliminate steady-state errors and improve the accuracy of the system.

too high of an integral gain can lead to overshoot and instability in the system's response

Derivative/Differential Control:

Derivative control is a type of feedback control that calculates the control action based on the rate of change of the error signal. The error signal is the difference between the desired setpoint and the measured process variable. The derivative controller calculates the control action by multiplying the derivative of the error signal by a constant gain factor.

$$u(t) = K_d \frac{d}{dt} e(t)$$

The derivative action produces a control action that is proportional to the rate of change of the error signal. This means that the controller responds to how quickly the error is changing, rather than its magnitude. This can help to improve the stability of the system and reduce overshoot.

too high of a derivative gain can lead to noise amplification and instability in the system's response

Advantages and disadvantages of Control algorithms:

Proportional, integral, and derivative control algorithms each have their own advantages and drawbacks.

Proportional control is simple to implement and can provide good performance for many systems. However, it can suffer from steady-state error and may not be able to completely eliminate the error between the setpoint and the process variable. Additionally, a high gain can cause the system to oscillate or become unstable.

Integral control can help to eliminate steady-state errors and improve the accuracy of the system. However, it can also introduce overshoot and increase the settling time of the system. Additionally, a high gain can cause the system to oscillate or become unstable.

Derivative control can improve the stability of the system and reduce overshoot. However, it can also amplify noise in the system and make it more sensitive to measurement errors. Additionally, derivative control alone is not sufficient to control a system and must be used in combination with proportional and/or integral control.

For better understanding of PID control :

What is a PID Controller?

PID Tuning:

PID tuning refers to the process of adjusting the gain parameters of a proportional-integral-derivative (PID) controller to achieve desired performance. A

PID controller calculates the control action by combining the proportional, integral, and derivative actions, each of which is determined by a separate gain parameter.

Tuning a PID controller involves adjusting the gain parameters to achieve the desired balance between responsiveness and stability. This can involve minimizing overshoot, settling time, and steady-state error while maintaining stability and avoiding oscillations.

There are several methods for tuning a PID controller, including manual tuning, Ziegler-Nichols tuning, and software-based optimization methods. The best method depends on the specific requirements of the system being controlled.

For understanding PID Tuning:
What are PID Tuning Parameters?