Birzeit University

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ENME 438 Control Theory

Introduction to Control Theory

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1 Introduction

Man is not the creator of control systems; theses systems exist in nature. Our body has several control systems such as:

1. Pancreas: It regulates blood sugar levels.
2. Adrenaline: Its level increases in addition to heart-rate at times of fight or flight, which causes more oxygen to be delivered to the cells.
3. Eyes: They can follow a moving object to keep it in view.
4. Hands and Arms: They can grasp objects and place them at a precise location.

These examples and others led to the idea of creating Automatic Control Systems.

1.1 Automatic Control Systems

Q: Why do we need control systems? Consider the following:

1. What good is an airplane if you are a pilot and you can't make it go where you want it to go?
2. What good is a chemical products production line if you can't control temperature, pressure and pH in the process?
3. What good is an oven if you can't control the temperature? (And, does it matter if it's an oven in a kitchen or an oven in a heat-treating department that is used to harden metal parts?)
4. What good is a pump if you can't control the flow rate it produces?

The common idea between all of the above cases is that there is a certain quantity (variable) that needs to be monitored, and, when needed, action should be taken.

1.2 Control System Examples

1. Water level in a tank.
2. Oven
3. Automated vehicles
4. Air-conditioning units
5. Robotic applications
6. Elevators etc.

2 Definitions and Terminology

1. **Controlled Variable**: the quantity that is measured and controlled (output of the system).
2. **Manipulated Variable (Control Signal)**: the quantity that is varied by the controller to affect the controlled variable.
3. **Control**: measuring the controlled variable, and applying a control signal to the system to correct or limit deviation of the measured value from the required value.
4. **Plant**: a set of parts functioning together to perform a particular operation (Physical System).
5. **Process**: an operation that we want to control.
6. **System**: a combination of components that act together to perform a certain objective. (Not necessarily physical, it could be biological, economic ..)
7. **Disturbance**: an unpredicted signal that affects the value of the output negatively.
8. **Feedback**: comparing the output to the input by calculating the difference between them, and bringing it close to zero.
9. **Control System**: a group of processes designed to obtain a desired output with a desired performance.

Figure 1: Simplified Description of a Control System

10. **System Response**: a representation of the performance of the system as a result of applying a certain input signal, which demonstrates the change of the controlled variable with respect to time.

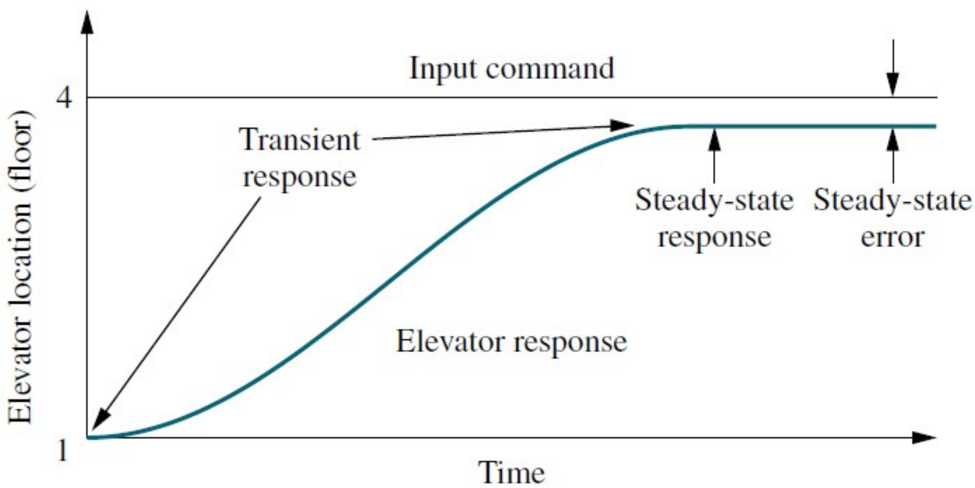


Figure 2: System Response Example (Elevator)

3 Control System Configurations

1. **Closed-Loop Control System**: this configuration includes feedback, which means that a change in the value of the output (controlled) variable will directly affect the input (manipulated) signal.

2. **Open-Loop Control System**: this configuration does not include feedback, which means that the output (controlled) variable has no effect on the input (manipulated) signal.

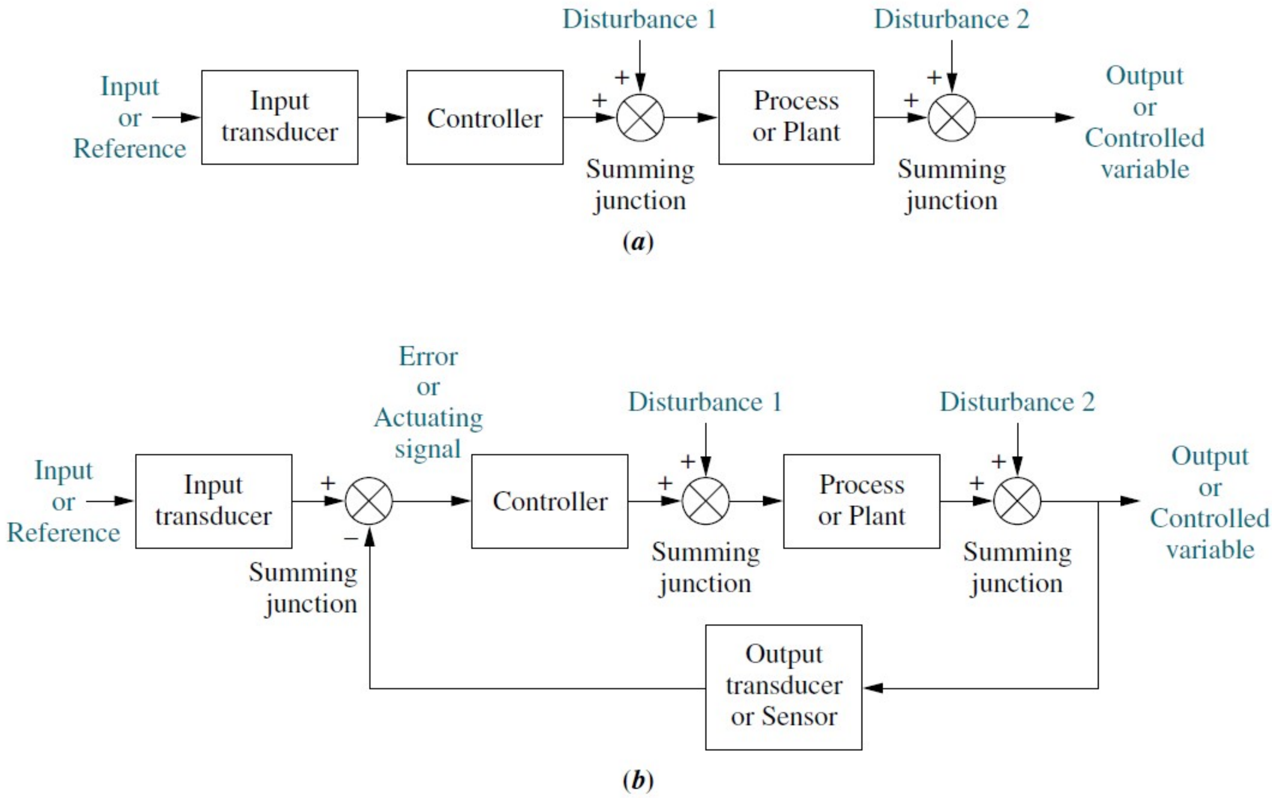


Figure 3: Block Diagrams of Control Systems: a. Open-Loop, b. Closed-Loop

3.1 Open-Loop vs. Closed-Loop

Configuration	**Pros**	**Cons**
Closed-Loop	Insensitive to disturbances	Stability problems
Open-Loop	Simple, Easy to maintain, Less expensive, No stability problems, Good when output is not easily measured	Sensitive to disturbances, Recalibration is often needed

4 Control System Design

4.1 Reasons for building control systems:

1. Power amplification.

2. Remote control.

3. Convenience of input form.

4. Compensation for disturbances.

4.2 Design Procedure:

1. Understand the requirements of performance.

2. Understand the physical system associated with the problem.

3. Create a schematic diagram.

4. Develop a mathematical model.

5. Draw a functional block diagram.

6. Reduce the block diagram.

7. Analyze and design using the help of test input signals shown in the table below.

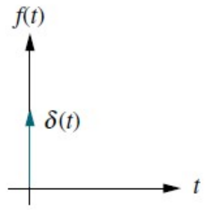
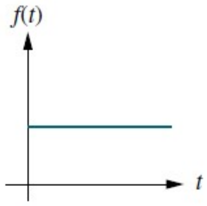
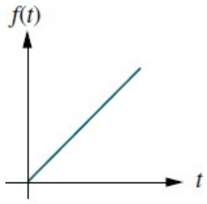
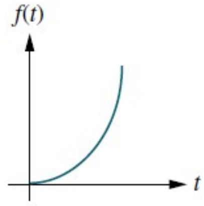
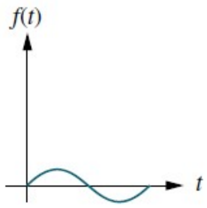
Input	Function	Description	Sketch	Use
Impulse	$\delta(t)$	$\delta(t) = \infty$ for $0- < t < 0+$ $= 0$ elsewhere $\int_{0-}^{0+} \delta(t)dt = 1$		Transient response Modeling
Step	$u(t)$	$u(t) = 1$ for $t > 0$ $= 0$ for $t < 0$		Transient response Steady-state error
Ramp	$tu(t)$	$tu(t) = t$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Parabola	$\frac{1}{2}t^2u(t)$	$\frac{1}{2}t^2u(t) = \frac{1}{2}t^2$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Sinusoid	$\sin \omega t$			Transient response Modeling Steady-state error

Figure 4: Test Waveforms used in Control Systems

4.3 Design Considerations

When designing a control system, you should keep in mind that we are trying to obtain:

1. Less steady-state error.
2. Better transient response.
3. Better stability.

References

[1] Dorf, R. C. and Bishop, R. H. (2008). Modern Control Systems (Eleventh Edition) *Pearson Education.*

[2] Ogata, K. (2010). Modern Control Engineering (Fifth Edition) *Pearson Education.*

[3] Nise, N. S. (2011). Control Systems Engineering (Sixth Edition) *John Wiley and Sons.*