Exercises for Chapter 1, *Applied Control Theory for Embedded Systems*

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An addendum to Applied Control Theory for Embedded Systems.

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Chapter 1 Problems

1. Find two examples of close-loop automatic control systems in or around your home. Describe them, explain why they are automatic control systems, and explain why they are closed loop.

2. Describe two examples each of an actuator, a plant, and a sensor. Explain your answers.

3. A CNC lathe consists of a computer that reads desired moves from an NC program and translates them into velocity and position commands. These commands are sent to electronic boxes that drive the motors that drive the various axes of the lathe. Each axis position and velocity is monitored with sensors and sent to the electronics boxes. Within each of the electronics boxes is a circuit which holds the operating voltages of the box steady, even as its input voltage varies.

   From this description, identify which part(s) of the system are executive controllers, which parts are regulators, and which parts are servo systems. Does the system contain a hierarchy of controllers?

Chapter 1 Answers

Problem 1:

1. My oven. I set it to a certain temperature, and the thermostat turns the heating element on until that temperature is reached or exceeded by a bit. When the oven temperature falls below the target temperature the thermostat turns the heat off.

   This is an automatic control system because once the target temperature is set by the human operator, the oven does the work of maintaining temperature. It is closed loop because a sensor value is used to control an actuator (the heater).

2. My home thermostat. We have a fancy heat pump with an equally fancy thermostat. It ramps up the heat pump output with variations in temperature, it schedules the temperature by the time of day, etc.

   It is an automatic closed-loop control system for reasons similar to the oven example, above.

3. The noise level in the house. With two energetic children things can get noisy. I attempt to maintain a certain maximum noise level; when the threshold is exceeded we then exert a number of different drive strategies, usually starting with gentle admonitions but sometimes culminating in time-outs to separate rooms or (on nice days) banishment to the out-of-doors. Duct tape has been considered, but not yet used.

   This is an automatic control system from my wife's point of view[1], because am less patient than she is with noisy children. It is closed loop because when things are quiet, I stop telling the kids to settle down!

4. The lowly flush toilet. We have too many of them. Each one has a number of different loops.

   (a) When the water level is low the float valve opens, allowing water into the storage tank. This valve closes when the water level reaches the target value (and you can adjust this by bending the lever to the valve).

       This is automatic because it requires no human intervention[2]. It is closed-loop because the float on the valve senses the water level, and exerts force on the valve to turn the water flow off.

   (b) When the actuator lever is depressed, water flows out of the tank until the ball valve has insufficient buoyancy to keep it up, whereupon it closes rapidly.

[1] At least when I am home
[2] normally

This is automatic because once started, the mechanism is responsible for continuing the cycle. It is closed loop because the ball valve only closes when the water level in the tank is sufficiently low (contrast this with a system that used a timer, which would be insensitive to water tank level).

(c) At this point the bowl can start filling again, but should the float valve fail to close, any excess water will spill over inside the drain to prevent overflow.

This is automatic because no intervention is required if the tank level exceeds the spillway. Feedback is very direct, in that water that exceeds the spillway height will — for purely physical reasons — flow downhill to the drain.

Problem 2:

1. Actuators:

   (a) A motorized valve, which changes fluid flow when properly driven.

   (b) A motor, which moves or generates torque when driven.

   (c) A heater, which emits heat when driven, thereby changing the temperature of the mass to which it is thermally coupled.

   (d) A control surface on an airplane, which changes the airplane's flight characteristics when driven.

   (e) An electrical solenoid, which exerts a force or moves when driven.

2. Plants

   (a) A tank who's level must be held constant

   (b) An airplane (for an autopilot)

   (c) An engine (for an engine management system)

   (d) A scan head (for a flatbed scanner)

3. Sensors

   (a) A potentiometer, which can be used to measure the angle of a shaft (or, through gearing, the position of an object).

   (b) A photo diode, which directly measures light level. Used properly, a photo diode can be used to indirectly measure any number of variables, given a suitable arrangement to change them into light levels.

   (c) An LVDT (Linear Variable Differential Transformer), which provides a nice noncontact measurement of linear displacement.

   (d) A resolver, which provides accurate angular measurement.

(e) A quadrature encoder (AKA "rotary encoder" or "linear encoder"), which provides accurate incremental angular measurements, and when coupled with a 'home' indicator provides absolute angular measurement.

(f) A thermometer, which measures temperature.

(g) A load cell (electronic weight scale), which uses a "proof ring" in conjunction with a precision linear displacement sensor (such as an LVDT) to measure force.

(h) A tachometer, which measures the rotary speed of a shaft.

Problem 3:

The computer is the executive controller, because it is translating the file into commands for the electronics boxes, the electronics boxes are servo controllers because while they are doing some minimal translating, they are mostly causing a plant to follow a command. The circuits within the electronics boxes that hold voltages steady are regulators, because their 'command' is preset, and does not change by design.

About the Author

Tim Wescott has 20 years of experience in industry, designing and implementing algorithms and systems for digital signal processing and closed loop servo control. His extensive practical experience in translating concepts from the highly abstract domain of mathematical systems analysis into working hardware gives him a unique ability to make these concepts clear for the working engineer.

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Applied Control Theory for Embedded Systems

This book is written for the practicing engineer who needs to develop working control systems without going back to school for years. It is aimed directly at software engineers who are learning control theory for the first time, however it has found favor engineers of all stripes when they are tasked with implementing control loops. It teaches theory, but it also covers many real-world issues in much greater depth than is taught in the sort of theory course you'd find in many universities.

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