Module 17

Introduction: Control Systems

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Educational Objectives:

UNDERSTAND Basic concepts of a control system
INTERFACE The tachometer and a DC motor
CREATE An integral control system using feedback
DESIGN A differential drive robot that will move in a straight line

Prerequisites (Modules 10, 12, 13, 15)

- Periodic interrupts using SysTick (Module 10)
- Mechanical and electrical interfaces of motors (Module 12)
- Timer_A PWM output (Module 13)
- Timer_A input capture period measurement (Module 15)

Recommended reading materials for students:

- Volume 1 Sections 4.1, 9.4, and 9.7
  Embedded Systems: Introduction to the MSP432 Microcontroller, ISBN: 978-1512185676, Jonathan Valvano, copyright (c) 2017

or

- Volume 2 Chapter 6
  Embedded Systems: Real-Time Interfacing to the MSP432 Microcontroller, ISBN: 978-1514676585, Jonathan Valvano, copyright (c) 2017

A **control system** is a collection of mechanical and electrical devices connected for the purpose of commanding, directing, or regulating a physical plant. The **state variables** are the properties of the physical plant that are to be controlled. In this module, we wish to spin the two motors at a prescribed speed. Thus, the state variable in this case will be motor speed. The **sensor** and **state estimator** comprise a data acquisition system. The goal of this data acquisition system is to estimate the state variables. We will attach tachometers to the motors so the system can measure speed of both motors. The estimated state variables, *X'(t)*, in this system will be the two measured speeds. The **actuator** is a transducer that converts the control system commands, *U(t)*, into driving forces, *V(t)*, that are applied the physical plant. We define the actuator command, *U(t)*, as the duty cycles for the PWM outputs to the two motors.

In general, the goal of the control system is to drive the real state variables to be equal to the desired state variables. In actuality though, the controller attempts to drive the estimated state variables to be equal the desired state variables. It is important to have an accurate state estimator, because any differences between the estimated state variables and the real state variables will translate directly into controller errors. We define the **error** as the difference between the desired and estimated state variables:

$$e(t) = X^*(t) - X'(t)$$

A closed-loop control system uses the output of the state estimator in a feedback loop to drive the errors to zero. The control system compares *X'(t)*, to the desired state variables, *X*(t)*, in order to decide appropriate action, *U(t)*. See Figure 1.

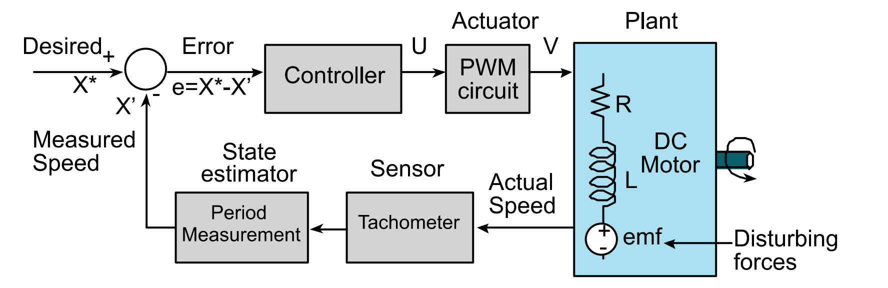

Figure 1. Block diagram of a MSP432-based closed-loop control system.

We can combine the period measurement from Module 15, the PWM output of Module 13, and the DC motor interface of Module 12 to build a motor controller. One effective yet simple control algorithm is an integral controller. We specify the actuator output as the integral of the accumulated errors.

$$U(t) = \int_0^t K_i E(\tau) d\tau$$

where K_i is a controller constant. For this controller, if the error is zero the actuator command remains constant. If the motor is spinning too slowly, the controller will increase power. If the motor is spinning too quickly, it will decrease power. For an integral controller, the amount of increase or decrease is linearly related to the error. So if the error is large it adds (or subtracts) a lot, and if the error is small it adds (or subtracts) a little.

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