TI-RSLK MAX
Texas Instruments Robotics System Learning Kit
Module 17

Lecture: Control Systems
Control Systems

You will learn in this module

- Introduction to control
  - Inputs
  - Control equations
  - Outputs

- DC motor control
  - Tuning

- Controller Performance
  - Stability
  - Accuracy
  - Time constant

\[ t_{\text{response}} \]

underdamped
Introduction to Control Systems

Microcomputers are widely employed in control systems:

- Automotive
  - Automatic breaking systems,
  - Ignition systems
  - Fuel systems
- Household appliances
- Industrial robots
- Medical devices
Control System Strategy

- Plant is a system that is intended to control
- Collect information concerning the plant – data acquisition system (DAS)
- Compare with desired performance
- Generate outputs to bring plant closer to desired performance
Control Theory
Performance Metrics

- **Accuracy** = steady-state controller error
  - Average difference between desired and actual
- **Time constant** = transient response
  - How quickly the system responds to change
- **Stability** = Standard deviation of controller error
  - System output changes smoothly – without oscillation or unlimited excursions

Response to change in setpoint, or change in load

- Underdamped
- Critically damped
- Overdamped
Motor Model

Duty cycle, $x(t)$ ➔ Motor ➔ Speed $y(t)$

Linear model
• Gain, $m$
• Time constant, $\tau$

Duty cycle, $X(s)$ ➔ Motor ➔ Speed $Y(s)$

$$H(s) = \frac{Y(s)}{X(s)} = \frac{m}{1+s\tau}$$

Motor

Motors are not linear
Friction affects everything

$$y(t) = S_0 + \Delta S \, e^{-t/\tau}$$
Motivation for a Control System

Power = Voltage * Current * DutyCycle

Motors are not linear
Friction affects everything
PID Control

\[ E = X^* - X' \]

\[ G(s) = K_p + K_d s + \frac{K_i}{s} \]

\[ \frac{X(s)}{X^*(s)} = \frac{G(s)H(s)}{1 + G(s)H(s)} \]

\[ H(s) = \frac{m}{1 + \tau s} \]

U = duty cycle to motor
Incremental Control of Motor Speed

Periodic interrupt

Measured = StateEstimator();

Error = Desired - Measured

Too fast

< -3

> 100

U = U - 100

at min

Too slow

> 3

< 14898

U = U + 100

at max

U

ok
General Approach to PID

\[ U(t) = K_p E(t) + \int_0^t K_i E(\tau) d\tau + K_d \frac{dE(t)}{dt} \]

- Proportional: \( U_p = K_p E \)
- Integral: \( U_i = U_i + K_i E \Delta t \)
- Derivative: \( U_d = K_d (E(n) - E(n-1))/\Delta t \)
- PID: \( U = U_p + U_i + U_d \)
- Run controller every \( \Delta t \)
- Run ten times faster than motor \( \tau \)
- Run slower or equal to sensor sampling rate
**Fixed-point math**

- **What is a fixed-point number**
  - value = integer*constant
  - constant has units, dimensional analysis

- **Why do we use fixed-point numbers**
  - Express non-integer values
  - Faster than floating point
  - Less expensive microcontroller

- **How do we use fixed-point numbers**
  - Range is small and known
  - Convert to integer math, divide last

\[ \pi = \frac{314159}{100000} \]

\[ U = 0.123e \rightarrow U = \frac{2015e}{16384} \]
Proportional Controller

\[ U(t) = K_0 + K_p E(t) \]

- Error \[ E = 250\text{mm} - D_R \]
- Proportional \[ U_L = 5000 - 8\times E \]
- Proportional \[ U_R = 5000 + 8\times E \]
  \[ 2000 \leq U_L \leq 7000 \]
  \[ 2000 \leq U_R \leq 7000 \]
- Controller period \[ \Delta t \leq \tau / 10 \]
- Run slower or equal to sensor sampling rate

Run controller every \( \Delta t \)
5000 is expected output
Integral Controller

\[ U(t) = \int_{0}^{t} K_i E(\tau) d\tau \]

- Error: \[ E = X^* - X' \]
- Integral: \[ U = U + K_i E \Delta t \]
- Antireset windup: \[ 2 \leq U \leq 14998 \]
- Controller period: \[ \Delta t \leq \tau / 10 \]
- Run slower or equal to sensor sampling rate

Run controller every \( \Delta t \)
Summary

Strategy of Proportional Control

- Get the direction correct
- If responsiveness is too slow, increase gain
- If over reacts, decrease gain

Strategy of Integral Control

- Add a lot to U if e is positive large
- Subtract a lot from U if e is negative large
- Add a little to U if e is positive small
- Subtract a little from U if e is negative small
- Leave U constant if e is zero

Advice

- Controller only as good as its sensor
- Observe everything “What was it thinking?”
- Change one parameter at a time
- Choose stability over responsiveness
IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2019, Texas Instruments Incorporated