EECS192 Lecture 9
Mar. 17, 2020

Notes:
1. Check off PCB Design Review I
2. Progress Report due Tues 4/7 before class in bcourses
3. HW 2 due Fri 4/3, 6 pm in bcourses
Topics
• Upcoming checkpoints
• HW 2
• Progress Report
• Linear regulator – recap
• Buck converter
• Flyback Diode for Motor Inductor
• Discrete Time control/timing
V-rep simulation- HW2

demo
Cones +2 second

Finish line: The start/finish line will be marked with two 4-inch-long segments of 1-inch-wide white tape that are parallel to the track with 1-inch spacing, as shown in the figure below.

The car must automatically stop within 6 feet of the finish line after finishing the race.

A penalty of 4 seconds will be added to the lap time for any car that does not automatically stop within the required region.
NATCAR Notes

1. Car can start in region shown (running start or avoid seeing stop line…) up to `several feet" behind start/stop line.

2. A running car can continue running for consecutive laps. If car is doing multiple laps without stopping, 4 second penalty is applied to intermediate laps.

The car must automatically stop within 6 feet of the finish line after finishing the race.

A penalty of 4 seconds will be added to the lap time for any car that does not automatically stop within the required region.
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Linear Voltage Regulator

\[ V_{IN} \rightarrow \text{regulator} \rightarrow V_{REG} = 5.0V \]

0.5 ohm (equiv. for 1 amp load)

\[ V_{REG} = 5.0V \]
Linear Regulator for RC servo power

- Power limit? Heat....

Caution: caps required for stability for some voltage regulators

\[ V_{IN} \rightarrow \text{regulator} \rightarrow V_{REG} = 5.0V \]

5 ohm (equiv. for 1 amp load)

\[ P_{diss} = ? \]

\[ V_{REG} \quad I_{IN} \quad P_{diss} \]

5.3 for LDO

\[ 10V \quad V_{IN} \]

\[ V_{IN} \quad V_{IN} \]
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Buck Converter- DC-DC

Why? Efficiency ~90%

Waveforms on board (also see buck converter notes.)
Buck: high to low. Boost: low-to-high)
Buck Converter

https://en.wikipedia.org/wiki/Buck_converter
Buck Converter
LM2678
LMR33630 Buck Converter
multiple capacitors can be used in parallel to bring the minimum effective capacitance up to the required value. This can also ease the RMS current requirements on a single capacitor.
Buck Converter Waveforms

**Figure 14. Typical PWM Switching Waveforms**

\[ V_{\text{IN}} = 12 \text{ V}, \quad V_{\text{OUT}} = 5 \text{ V}, \quad I_{\text{OUT}} = 3 \text{ A}, \quad f_S = 400 \text{ kHz} \]
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Low side motor drive

What about motor inductance?
Flyback diode with motor model

Motor inductance ~ 100 uH (?)

Time constant?

$L/R = 10^{-4} \text{H} / 0.1 \text{ ohm} = 1 \text{ ms}$

$V_{DS} = 10V - V_{\text{DIODE}}$

Sw

Closed

Open

6.5 amp

5 amp

$i_m$

7.5V

$V_L$

-2.65V

0

20 us

57 us

t
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Control Synopsis

State equations:

\[ \dot{x}(t) = ax(t) + bu(t) \]

Output equations:

\[ y(t) = cx(t) + du(t) \]

Control Law (P):

\[ u(t) = k_p e(t) = k_p (r(t) - y(t)) \]
Control Law (P):

\[ u(t) = k_p e(t) = k_p (r(t) - y(t)). \]

New state equations:

\[ \dot{x} = ax + bk_p e(t) = ax + bk_p (r - x) = (a - bk_p) x + bk_p r. \]

Zero Input Response (non-zero init condx):

\[ x(t) = x(0) e^{(a - bk_p)t} \quad \text{for} \quad t \geq 0. \]

\( a' = a - b k_p \quad b' = b k_p \)

Total Response (non-zero init condx) by convolution:

\[ x(t_o) = e^{a't_o} x(0) + \int_0^{t_o} e^{a'(t_o - \tau)} b' r(\tau) d\tau. \quad (10) \]

Step Response (zero init condx) by convolution:

\[ x(t_o) = b' \int_0^{t_o} e^{a't_o} e^{-a'\tau} d\tau = \frac{-b'}{a'} e^{a't_o} \bigg|_0^{t_o} = \frac{b'}{a'} (1 - e^{-a't_o}). \quad (11) \]
Control Synopsis- Discrete Time

Superposition of Step Responses

\[
x((k+1)T) = e^{a(k+1)T}x(0) + e^{a(k+1)T} \int_0^{(k+1)T} e^{-a\tau} bu(\tau) d\tau.
\] (15)

\[
x(kT) = e^{akT}x(0) + e^{akT} \int_0^{kT} e^{-a\tau} bu(\tau) d\tau.
\] (14)

\[
x((k+1)T) = e^{aT}x(kT) + e^{a(k+1)T} \int_{kT}^{(k+1)T} e^{-a\tau} bu(\tau) d\tau = e^{aT}x(kT) + \int_0^{T} e^{a\lambda} bu(kT) d\lambda,
\] (16)
Control Synopsis- Discrete Time

\[ G(T) \equiv e^{aT} \quad \text{and} \quad H(T) \equiv b \int_0^T e^{a\lambda} d\lambda. \] (17)

State equations:

\[ x((k + 1)T) = G(T)x(kT) + H(T)u(kT) \] (18)

Output equations:

\[ y(kT) = Cx(kT) + Du(kT). \] (19)

Total Response (non-zero init condx) by convolution:

\[ x(k) = G^k x(0) + \sum_{j=0}^{k-1} G^{k-j-1} Hu(j). \] (23)
Control Synopsis - Discrete Time

Control Law (P):

\[ U(kT) = k_p [r(kT) - x(kT)] \]

New state equations:

\[ x((k + 1)T) = G(T)x(kT) + H(T)k_p(r(kT) - x(kT)) = [G - Hk_p]x(kT) + Hk_p r(kT) . \quad (24) \]

\[ x((k + 1)T) = [e^{aT} + \frac{k_p}{a}(1 - e^{aT})]x(kT) + Hk_p r(kT) = G'x(kT) + Hk_p r(kT) . \quad (25) \]

For stability:

\[ |e^{aT} - \frac{k_p}{a}(e^{aT} - 1)| < 1. \quad (26) \]

Notes: stability depends on gain and \( T \)!
Discrete Time Control

\[ u[k] = kp \times (r[k] - x[k]) \]

On board