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RBE 1001: Introduction to Robotics
C-Term 2019-20
Fundamentals of Circuits for Robotics

Introduction

Along with programming and mechanics, electronics is the third "pillar" in the foundation of robotics. These assignments are designed to help you learn some of the fundamentals so that we can spend class time applying them to robotics. As before, we have provided resources and review problems to help you learn the material, and you can always meet with an instructor to get more thorough explanations. If you have a solid background in electronics, on the other hand, then you might just want to skim some of the materials herein and jump straight to the problems to submit.

Resources

The following materials are available online. Don't worry – you don't have to read all of it! Much of the material in them is similar, but we want to give you a chance to find a resource you're comfortable with. Practice problems are selected from these resources.

- *Understanding Circuits Learning Problem Solving Using Circuit Analysis* by Khalid Sayood (1st ed) - A good option if you've seen circuits before but need a refresher.
- *Introduction to Circuit Analysis and Design* by Tildon H. Glisson (1st ed) - A very thorough look at circuits, great for anyone who needs to know why things work the way they do.
- *Introduction to Electrical Circuit Analysis* by Ozgur Ergul - A calculus-based introduction to circuits, this is ideal for students who have already taken college-level calculus and physics and aren't worried by integrals.

Fundmentals

Electricity and Charge

It is not necessary to have a complete understanding of the physics behind electricity, but you need to understand the key concepts: voltage, current and resistance.

If you prefer to have a more complete sense of the fundamental physics, the following are good resources:

- Sayood 2.2,
- Glisson 2.1 - the rest of Chapter 2 presents more detail of the physics of circuit components,

Ohm's Law

For a purely resistive element, the current, voltage resistance are famously related by Ohm's Law,

$$\Delta V = IR$$

A common mistake is to simply apply $V = IR$ to an element – since one end of the resistor is often connected to ground, which we usually take to be 0 V, then the equation works out anyway. But be careful when a resistor is placed between two non-zero voltages – it's the *difference* in voltages that drives the current.

For review or a more thorough explanation, consult,

- Sayood 3.2, 3.3;
- Glisson 2.4;

If you prefer a more casual introduction, Khan Academy has a great introduction to circuits.

Circuit Diagrams

If you are unfamiliar with circuit diagrams, review,

- Glisson 3.1-3.6, and/or
- Ergul 1.5.

Kirchoff's Laws and Node Analysis

Kirchoff's Voltage Law (KVL) and Kirchoff's Current Law (KCL) are very helpful tools for circuit analysis (i.e. figuring out what the heck that circuit does). Using KVL and KCL for circuit analysis is sometimes called node analysis, because the laws treat circuits like a set of connected nodes. Review any of the following:

- Sayood 2.3
- Glisson 3.7, 3.8
- Ergul 2.*

To check your understanding, work through any of the following problems (answers provided):

- Sayood 2.5: 1-8
  1. $I_0 = 2$mA
  2. $I_0 = 4$mA
  3. $V_0 = 4$V

4. $V_0 = 3$V
5. $I_0 = 2$mA
6. $I_0 = 6$A (assume circuit is connected)
7. $V_0 = 18$V
8. $V_0 = -9$V

- Glisson 3.11: 3.2-3.7, 3.10, 3.14, 3.21, 3.31
  - Assume v_a is the voltage at node a with respect to the reference node, and v_{ab} is the voltage *difference* between nodes a and b.

3.2. $v_e = v_d$, $v_f = v_b$, $v_g = v_d$, $v_h = v_a$

3.3. $v_a = 10V$, $v_b = 6V$, $v_c = 4V$, $v_d = 4V$, $v_e = 10V$, $v_f = 1V$, $v_g = 4V$, $v_h = 10V$, $v_i = 1V$,

3.4. $v_a = 2V$, $v_b = 5V$, $v_c = 3V$, $v_d = 5V$, $v_e = 5V$, $v_f = 3V$, $v_g = 10V$, $v_h = 3V$, $v_i = 6V$, $v_j = 2V$, $v_k = 10V$, $v_l = 2V$

3.5. $v_e = 12V$, $v_f = 10V$, $v_{bh} = -5V$, $v_{dh} = -3V$, $v_{fh} = -5V$, $v_{ca} = -25V$

3.6. $v_{ab} = 4V$, $v_{bg} = 2V$, $v_{cf} = 3V$, $v_{cd} = 0V$, $v_{fe} = -9V$, $v_a = 9V$, $v_b = 5V$, $v_c = 3V$, $v_f = 0V$, $v_h = 9V$

3.7. $v_a = -8V$, $v_d = -5V$, $v_h = -7V$, $v_g = 0V$, $v_{bd} = 0V$, $v_{dg} = -5V$, $v_{ih} = 3V$, $v_{bf} = 2V$

3.10. $1 + 2$ means element 1 is in series with element 2, $1||2$ means element 1 is in parallel with element 2. (a) $1 + (2||3) + 4$. (b) $1 + 2 + (3||(4 + 5))$. (c) None are in series or in parallel. (d) $1||(2 + 3)||4$

3.14. (a) $v_{lamp} = 0V$, $i_{lamp} = 0A$ (b) $v_{lamp} = v_0$, $i_{lamp} = \frac{v_0}{R}$

3.21. $i_1 = -4.5mA$, $i_2 = 2mA$, $i_3 = -.25mA$, $i_4 = 1.667mA$, $i_5 = -3.75mA$, $i_6 = 10mA$, $v_{ab} = 5V$, $v_{bc} = -15V$, $v_{ac} = -10V$

3.31. $v_L = i_L R_S - v_S$

- Ergul Chapter 2 Exercises 3,5, 6 9pp. 34-35) and 8, 9 (p. 44)

Exercise 3 $R = \frac{2}{3}\Omega$

Exercise 5 $i_x = 1.48A$ - careful not to round until the very end, otherwise error will build up!

Exercise 6 $i_x = 14A$

Exercise 8 $i_x = 1.5A$

Exercise 9 $i_x = 6.17A$

HW 3.0: Assigned Problems

1. Sayood, Section 2.5 (p. 26), Exercise 9
2. Ergul Chapter 2 (p. 34), Exercises 2 and 4

Power and Energy

It is important to understand power and energy as they relate to electronic circuits. Not only do you need to check that you're not overtaxing a component with too high of a voltage or current, but understanding power is essential to designing motors and battery subsystems. Refer to Glisson 5.1 and 5.2.

Practice Problems & Answers: In Glisson, Chapter 5 (Section 5.18, "Problems", starting on p. 148)

- 5.7: $p_1 = \frac{v_0^2}{R_1}$ and $p_2 = \frac{v_0^2}{R_2}$
- 5.9 $I = \sqrt{P/R} = 0.0224\mathrm{A}$ and $V = \sqrt{PR} = 22.4\mathrm{V}$
- 5.11 Number the resistors from left to right as R_1, R_2, R_3, R_4. $P_1 = V_0 I_0/2$ is the largest. For comparison $P_2 = V_0 I_0/4$ and $P_3 = P_4 = V_0 I_0/8$.
- 5.15 $P_{\text{series}} = R_e q I^2 = 2RI^2 = 2P$
- 5.16 $P_{\text{parlallel}} = V^2/R_e q = V^2(1/R + 1/R) = 2V^2/R = 2P$

HW 3.1: Assigned Problems

In Glisson, Chapter 5 (p. 149),

1. Glisson 5.12
2. Glisson 5.13

Voltage Dividers

A voltage divider is a common circuit – probably the most common that you will encounter – that is used for voltage regulation, in feedback loops, and in sensor conditioning circuits, among other uses. You will need to be very comfortable with calculating voltages – or the resistors needed to produce a particular voltage. In short, a voltage divider is an application of KCL and takes advantage of a proportional relationship between two resistors in series to help us solve the mathematical relationships. For more details, consult any of the following:

- Sayood 3.4; and/or
- Glisson 3.9.

There are also some good explanations of Voltage Dividers on SparkFun, a electronics hobby site, and Khan Academy.

To check your understanding, work through any of the following problems (answers provided):

- Sayood 3.6 (p. 47): 6, 7, 9

6. $V_R = 1.275$V (this one is tough, circle back to it)
7. $V = 13$V (you shouldn't need a calculator)
9. $I_0 = 0.2$A (flowing through the 10Ω resistor)

- Glisson 3.11: 3.23 (p. 73)

  3.23. In order for half of v_S to be dropped across the load resistance R_L (and therefore across kR simultaneously), the other half of v_S is dropped across the resistance $(1-k)R$. Therefore, the resistance $(1-k)R$ must be equal to the parallel resistance of kR and R_L.

  $$(1-k)R = \frac{kR(R_L)}{kR + R_L}$$

  $$(kR + R_L)(1-k) = kR_L$$

  A calculator can solve from there.

- *Additional Practice Problems* (solutions available upon request)

HW 3.2: Assigned Problems

1. Sayood 3.12 (p. 48)
2. Sayood 3.16 (p. 50)