LECTURE NOTES

ELEC1100: Introduction to Electro-Robot Design

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September 16, 2025

- If the amount of charge change when moving, how do we count the energy?(For last lecture)
- A Loop containing 2 sources?
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Contents

1 Basic Electronics

1.1 Basic Components

Current is the orderly movement of charged particles and is equal to the rate of flow of charges. Different items with different ability for charge to flow are categorized in to conductors and insulators. This ability is described as **resistance**[1].

Principle 1.1. Important formula:

$$I = \frac{\Delta q}{\Delta t} \tag{1}$$

$$R = \rho \times \frac{L}{A} \tag{2}$$

$$I = \frac{V}{R} \tag{3}$$

By convention, **current direction** corresponds to the direction of positive charges move. In other word, the current flow and the electron flows the opposite direction.

Note 1.1. Smallest amount of charge is the charge of 1 proton. $q = 1.6 \times 10^{-19}$

Voltage is the force generated by the difference in electric potential between 2 points that makes electrons move through a conductor. By convention we define a point in a circuit as a reference point which is known as GND (ground) and carries a voltage of 0V.[2]

Note 1.2. A **battery** uses its internal chemical energy to move the electrons in order to have a continuous current flow. A **capacitor** is a passive device that can store electrical energy when connected to a voltage source.

There are 2 basic ways for resistors to combine together: **Resistors in series** and **Resistors in parallel**. Different ways of connection can lead to different total resistance.

[1] More information about resistor Here

[2] More information about GND Here

1.2 Energy & Power

Robots gain energy from battery. Batteries can only provide DC(Direct Current).[3] Robots and other electronic devices need energy.

Principle 1.2. Energy is the ability to do work.[a] **Power** is the rate of energy consumption in a circuit.

$$E = \Delta q \times V \tag{4}$$

$$P = \frac{E}{\Delta t} = \frac{\Delta q \times V}{\Delta t} = I \times V \tag{5}$$

[a] In the study of electronic, voltage is the force that makes electrons move in a circuit, which gives the electrical energy transfer of moving charges. So the potential energy is equal to the work needed to move a charge.

When a current flow through a resistor, the electric energy will turn into heat.

Principle 1.3. By Ohm's Law, power dissipated by resistor:

$$P_{Heat} = I^2 R \tag{6}$$

$$P_{Heat} = \frac{V^2}{R} \tag{7}$$

1.3 Circuit Laws: KCL & KVL

By the idea of equivalent resistance, we can simplify circuit to find the total current. However, many complex circuits cannot be analyzed with the series-parallel techniques. We will need to use the Kirchhoff's Laws.

Note 1.3. Kirchhoff's Law
KCL(Current Law): The junction rule: The sum if all currents entering a junction must equal to the sum of all currents leaving the junction.
KVL(Voltage Law): The loop rule: The algebraic sum of changes in potential around any closed circuit path must be 0;

$$\sum I_{in} = \sum I_{out} \tag{8}$$

$$\sum V = 0 \tag{9}$$

To apply KVL, we need to find several loops that could together cover all the electrical appliances. (including power supply and resistor) Each loop should be counted in one direction. Pay special attention to the power supply. The voltage drop from positive to negative and rise from negative to positive.

To apply KCL, wisely choose several nodes that cover all the currents.

Applying these rules can help us easily solve the resistance of complex electrical circuit. Even solving multi-power supply questions.

[3] Changing voltage in AC Here and changing voltage in DC Here

2 Motor Power Supply

2.1 DC Regulation

DC are current with constant voltage. The most common type of DC power sources is a battery. Consider that we connect voltage sources in different ways (in series and parallel). The following picture shows how they are connected. It is important to note that only ideal voltage sources of the same value can be connected in parallel, while there is no such restriction to connecting in series.

In real life, however, battery voltage is not always constant. A battery will slowly lose its charge, meaning that the voltage will drop as the battery is discharged. Its performance also can change dramatically with temperature. Meanwhile, a battery has its own resistance which will increase by time, affecting its output. For a more stable DC supply, we use computer controlling AC adapters to convert AC power from a wall outlet into DC power.

Battery, however, is still widely used in real life. Thus, we need a regulator to provide a predictable and constant voltage. Now we look into some components used as voltage regulators.

2.2 Diode

Note 2.1. Voltage regulator: Diode
A diode is a device that only allows current to flow in **one direction**. There is a black strip representing the negative side (or technically, **cathode**). The symbol of diode is shown as follow.

In the circuit, a diode becomes a short circuit when forward biased and an open circuit when reverse biased. In signal, forward biased means 0 voltage, reverse biased means 0 current.

For example, LED only emits light when current flow from anode(positive side with longer lead) to cathode(negative side with shorter lead).

In real life experiment, however, we usually need 0.7V to turn on the diode. In other words, when forward biased, the voltage drop V_{on} across a real/practical diode is about 0.7V. In circuit analysis, we can consider it as a 0.7 voltage power supply.

Similar to the diode, a zener diode allows current to flow from anode to cathode but also allows current to flow reversely when the reverse voltage is larger than the zener breakdown voltage V_{BD}.

The zener diode is useful to regulate the source voltage. The following shows a zener diode voltage regulator circuit. Note that the Zener diode should be reversely connected into the circuit to have $|-V| > |V_{BD}|$

We use zener to make DC to DC conversion, controlling the voltage of certain circuit. In real life, however, zener diode has a relatively poor regulation ratio. IC(Integrated Circuit) is more efficient and widely used. We measure the performance of a regulator by line reculation and load regulation.

Note 2.2. Line regulation $= \frac{\Delta V_O}{\Delta V_I}$ and Load regulation $= \frac{\Delta V_O}{\Delta I_O}$

2.3 Transistors

A diode is also called as "PN junction diode", which is formed when the P-type and N-type semiconductors are joined(The barrier potential is roughly 0.7 voltage which means there will be a voltage drop inside the diode).

When we add another layer to a PN junction diode, it forms a 3-terminal device called a transistor, which is normally refers to a Bipolar Junction Transistor(BJT). These 3 terminals are labeled as Collector(C), Base(B) and Emitter(E). Different ways of adding layer result in 2 different types of standard BJT: NPN and PNP. The semiconductor materials allow the transistor to **amplifies** or **switches** the flow of current. We will see their function later on. The conductivity between 2 of the terminals is controlled by the third terminal.

All transistors have 3 modes of operation:

- Off mode: No base current
- Amplification mode: Current in B cause changes in current in C and $I_C = \beta I_B$
- Saturation mode:I_C reaches its max and remains nearly constant.

The B-E terminal of NPN behaves like a diode. A high voltage given to the B terminal allows a switch to be turned on. For PNP. E-B terminal behaves like a diode, and terminal B needs a low voltage. So the external voltage determine the state of on and off.

Transistor can also be used as amplifiers.

This will continue until it reaches it highest possible current in C. A transistor will drop about 0.2V across the collector-emitter (C-E) terminal when in saturation mode (fully on). So the lowest possible voltage at C should be 0.2V.

One thing that might confused you is where the current in C come from. Please note that the current in C does not come from the current in B, which means the amplifier is not actually an amplifier, it still need an external power source.

Due to its property shown above(input voltage and output voltage is invert), NPN transistor circuit can be used to construct another device called Inverter. In the circuit symbol, the triangle represent the amplifier and the circle means inverter. When the input voltage is high, the output voltage is low. Normally we need 2 external voltage to make inverter work. One is used as the power source, while the other is used as the signal.

In this course, we use IC 74HC14 to work together with the H-bridge to control the robot car motors. The structure of 74HC14 is shown below. There are 6 inverters inside the package and they are independent to each other. These inverters are connected to 14 pins where by convention, pin 7 connecting to GND and pin 14 connect to external power source.

2.4 H-Bridge

Transistor type	PNP	NPN
External voltage signal	High	High
On/Off	Off	On

Table 1: Transistor's Mode Under Different Voltage

H-Bridge circuit is a simple circuit that lets you control a motor to go backward or forward. When the circuit flow from positive to negative, it goes forward. When flowing the opposite direction, it goes backward. The following picture use switches to show the state of the circuit being turned on and off. And in a more complex circuit they are actually transistors(used as switch).

- Q1, Q3: PNP transistors (The positive side should connect with the power source)
- Q2, Q4: NPN transistors (similarly, the negative side connect to the GND)
- VCC is stable and provide power supply
- Voltage in Q1, Q2 is low and Q3, Q4 is high: Current goes through one direction
- Voltage in Q1, Q2 is high and Q3, Q4 is low: Current goes through opposite direction

Let us suppose that the high voltage is 5V and low voltage is 0V. Through transistors, we can transfer the action of controlling 4 switches into controlling 2 value of signal voltage. To make it more convenient, we use inverter to get 2 value of voltage.

2.5 DC Motors

A **motor** is an electric-mechanical device, converting electrical energy into mechanical energy. It can be classified into DC and AC motors by power source. The brushed motors powered by DC will be used in this course. An electronic motor operates through the interaction of the magnetic fields of a stator and a rotor.

Note 2.3. Stator, rotor, commutator and brushes
They can generate a dynamic magnetic field, which is called commutation, in the rotor and keep it spinning.

2.6 Pulse & PWM

To control the motor rotation direction, we can reverse the current direction flowing into the motor. And to control the motor rotation speed, we can regulate the voltage across the motor terminals. One trivial way is to regulate through variable resistor which is not efficient. PWM technique is introduced to solve this problem.

Note 2.4. Pulse signal and PWM

A pulse signal is formed by a rapid or sudden transient changes between its high and low levels, leading to a square/rectangular waveform.

$$\begin{cases} \text{High time} = H \\ \text{Low time} = L \\ \text{Time period} = H + L \\ \text{Frequency} = \frac{1}{T} \\ \text{Duty Cycle} = \frac{H}{T} \text{ Time period that is on} \end{cases}$$

One of the applications of pulse voltage is to control the brightness of a light. The change in duty cycle will change the average voltage and thus change the equivalent voltage which directly effect the power.

PWM(Pulse Width Modulation) changes the width of a pulse according to the requirement.

When a pulse voltage is applied to a DC motor, the rotation speed of the motor is directly proportional to the average voltage value on the terminals.

A positive pulse can be generated mechanically by using a switch. By electrical means we use oscillator. But these analog control is difficult to obtain the required speed precisely. So we need to control the pulse width digitally. [4] There are many advantages (cheap, large storage, high speed data processing) using digital signals and that is the result they are widely used nowadays.

3 Sensors

Sensor is a device that measures or detects a real-world condition. It tells a robot one simple thing about its environment: temperature,distance,light intensity,etc. It allows robots to see and feel the physical world through which they travel.

In the final project, we will use **light sensors**. Light sensors are photo-electric device that converts light energy detected to electrical energy, in the micro world, photons to electrons.

Note 3.1. Lumen and Lux:

They are both describing the brightness. Lumen is a measure of total amount of light emitted in all directions. Lux is a measure of light falls on a surface.

The most common light sensor type are photo-resistors, also known as a **light-dependent resistor(LDR)**. It is made of a high resistance semiconductor material called cadmium sulfide cells, highly sensitive to visible and near-infrared light that changes its electrical resistance from several thousand Ohms in the dark to only a few hundred Ohms when light falls upon it.

We can use NPN transistor to form a dark or a bright sensing circuit.

[4] Digital control systems deals with discrete signals having binary values.

Another important sensor is the IR sensor to detect infrared radiation in its surrounding environment. It emits IR which hits the objects and is reflected back by that object which is detected by the receiver.

Data sampling of the signals will be transferred into digital signal.

4 Control Logic

4.1 Boolean Algebra and Logic Operators

We use logic control system to generate control signals. Boolean Algebra is the mathematics we use to analyze and simplify the digital (logic) circuit.

A logic input (0/1) can be combined with another logic input in different ways to form a new logic input. This combination of the inputs are logic gates.

It is trivial that NOT gate is an inverter and need 1 input. AND gate and OR gate needs 2 inputs while generating 1 output.

For logic control system design for our car project, the logic output can be simplified as follows:

Sensors	L DIR	R DIR
0 0	1	1
0 1	1	0
1 0	0	1
1 1	0	1

Table 2: Logic Control System

Note 4.1. Combinational Logic
It is a control logic that the outputs depend **only on the current inputs of the circuits, but not on the history of the inputs**. As soon as the inputs change their values, the outputs will be affected. For example, the DIR control is a conbinational logic system.

An important combinational logic control system is the **half adder**. It adds the two bits A and B and gives the **sum** and **carry** bits as the outputs.

According to its truth table, the logic for sum and carry as well as the gates it's using should be as follows:

$$S = (A \oplus B) \text{ and } C = A \cdot B$$

A stronger adder that can carry the incoming carry from the previous addition is **full adder**. It is also a combinational logic circuit which adds tow bits A and B, along with the incoming carry bitC_{in}, and generates the **sum** and **carry** bits as the outputs.

4.2 MCU and Arduino

Logic gate is powerful, but you can imagine the tremendous workload if a more complicated robot system is required. It's a nightmare to build, test, and debug, and it won't be very powerful. This is the reason why MCU (micro-controller unit) will be used (by writing in C++ language) to replace the logic gate circuits in our project.

4.3 Arduino Programming