# Mechatronics Project Guideline

**Project week:** June 17, 2021 to June 23, 2021
**Lab time:** June 17 10:15-11:55
June 22, 8:30-10:00
June 18, 21, 23 14:00-16:00
**Project demo:** June 24, 2021 10:15-11:55

## 1. Introduction

### 1.1 Coolant Temperature Control

Suppose you are an engineer of a "Smart Manufacturing" team. Recently, your team got a job to improve the cooling system of an IT infrastructure and data center, as shown in Figure 1. In order to save some energy consumption, the objective is to control the cooling system (of the coolant) smartly depending on the temperature of the coolant temperature (and the presence of human operators).

Figure 1 IT data center

Since most electronics prefer to work under 50℃, please design your control logic so that a cooling-fan motor turns on when the coolant is 8℃ above the room temperature (25℃). Moreover, the cooling-fan motor speed should increase accordingly if the coolant temperature keeps rising and reach its maximum speed when the coolant temperature rises to 45℃. Please use a provided temperature sensor to detect the temperature.

Figure 2 Human operator workspace

### 1.2 Human Presence Detection

Let's say the coolant cooling system is very powerful. It is obvious that the coolant temperature would stay between 32℃ and 50℃. These temperatures are okay for electronics but create a hard time for human operators. To solve this problem, your team plans to install an infrared photoelectric sensor at the operator's workplace, as shown in Figure 2. If the operator is present, the sensor would be triggered. Your job is to improve the previous control logic: set the motor speed at its maximum if photoelectric sensor is triggered, regardless of the temperature sensor.

## 2 Required Material and Tools

### 2.1 Material List:

- Motor with a fan
- PT100 resistance temperature detector
- Temperature reader
- Triode (Transistor)
- Infrared photoelectric sensor
- Connection cables
- Bottle of hot water
- Glass thermometer

### 2.2 Equipment List:

- Elvis III workbench
- Prototyping board
- Computer with LabVIEW

## 3. Technical Approaches
### 3.1 PT 100 Resistance Temperature Detector (RTD)

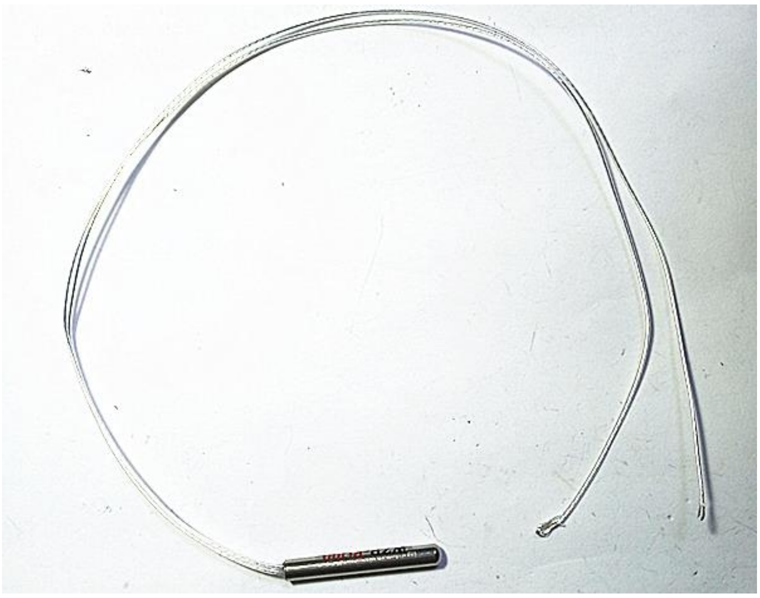


Figure 3 PT 100 RTD

The PT 100 RTD is a platinum based RTD sensor, as shown in Figure 3. Platinum is a noble metal and offers excellent performance over a wide temperature range. Platinum also features the highest resistivity of commonly used RTD materials, requiring less material to create desirable resistance values. The PT 100 RTD has an impedance of 100 Ω at 0°C and roughly 0.385 Ω of resistance change per 1°C change in temperature. The resistance is 18.51 Ω at -200°C and 390.48 Ω at 850°C. Higher-valued resistance sensors, such as PT 1000 or PT 5000 can be used for increased sensitivity and resolution. PT 100 RTDs are a good choice for this application to provide good pre-calibration accuracy and long-term stability.

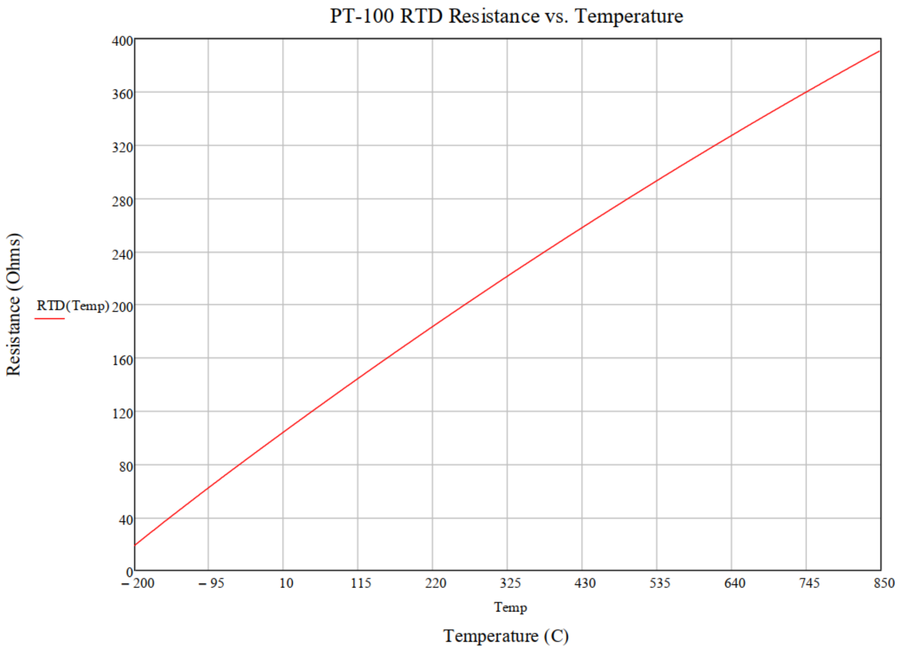



Figure 4 PT 100 RTD resistance from -200°C to 850°C

A PT 100 RTD will have less than 0.5°C of error at 100°C without calibration and the long-term stability makes infrequent calibration possible. The change in resistance of a PT100 RTD from -200°C to 850°C is displayed in Figure 4.

### 3.2 Infrared Photoelectric Sensor

The reflective infrared photoelectric sensor is to be used. According to its principle and internal structure, we can design the circuit as shown in Figure 6. The resistance is mainly used to limit the current, and the resistance value is usually set as R1 = 510 Ω, R2 = 25K Ω. If the receiver receives the reflected infrared, the infrared receiver is on, and the E pin outputs high level, which is close to VCC； if the receiver does not receive the reflected infrared, the infrared receiver is not on, and the E pin outputs low level, which is close to GND. White matter absorbs less light and most light waves are reflected; black matter can absorb most light waves and only part of them are reflected. To make use of this, we should use black material to block the infrared in this experiment.

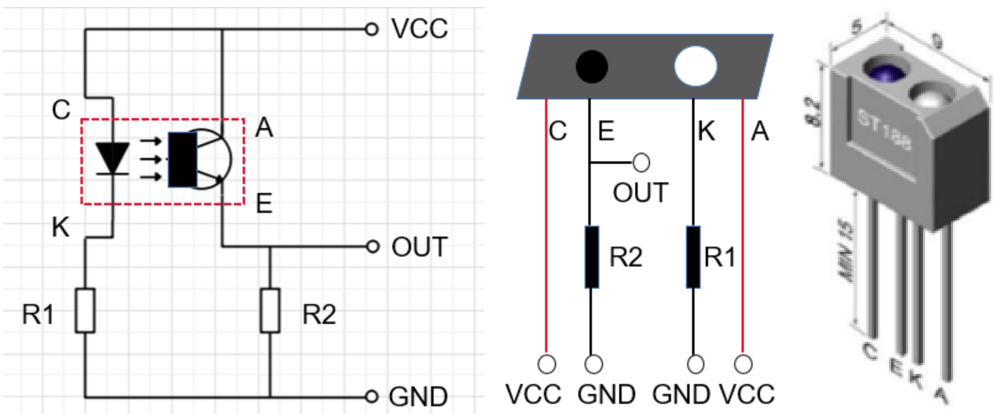



Figure 5 The wire connection of infrared sensor module

### 3.3 Triode (Transistors)

Transistors are three-pin active electrical devices. Figure 6 shows a particular type of transistor that we will use for the lab today. It has three pinouts: the Base (B), Collector (C) and Emitter (E). There are various types of transistors, and they can be configured in different ways. Typically, a transistor is used as an amplifier or a switch. You can think of one of the pins as controlling the current flow through the other two. Ideally the "input" pin doesn't draw any current. We say such a device has "infinite input impedance." Also ideally, the output voltage characteristics don't depend on the current

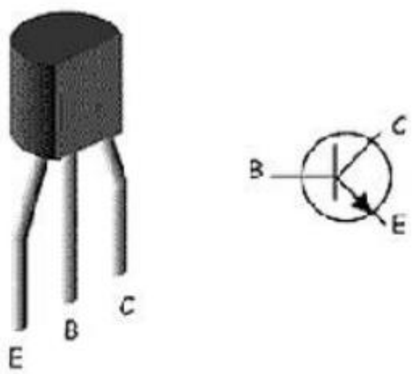



Figure 6 Typical transistor pin-out diagram

being drawn. We say that such a device has "zero output impedance." Ideal switches and amplifiers have infinite input impedance and zero output impedance.

Triode, the full name should be semiconductor triode, also known as bipolar transistor, crystal triode, is a kind of current control current semiconductor device, its role is to amplify the weak signal into a larger amplitude value of electrical signal. As one of the basic components of semiconductor, it has the function of current amplification and is the core component of electronic circuit. Triode is to make two PN junctions which are very close to each other on a semiconductor substrate. The two PN junctions divide the whole semiconductor into three parts. The middle part is the base region, and the two sides are the emitter region and the collector region.

There are two kinds of arrangements: PNP and NPN. The SS8050 in-line NPN triode is used in this experiment. The following analysis is only for NPN transistor. As shown in Figure 7, the current flowing from base B to emitter E is called base current $I_b$, and the current flowing from collector C to emitter E is called collector current $I_c$. The two directions of the current flow out of the emitter, so there is an arrow on the emitter E to indicate the direction of the current. The amplification function of triode is: the collector current is controlled by the base current (assuming that the power supply can provide enough current for the collector), and a small change in the base current will cause a large change in the collector current, and the change satisfies a certain proportional relationship: the change of the collector current is β times of the change of the base current, that is, the current change is amplified by β times, Therefore, we call β the magnification of triode (β is generally much greater than 1, for example, tens or hundreds). If we add a changing small signal between the base and emitter, it will cause a change in the base current $I_b$. After the change is amplified, it leads to a big change. If the collector current $I_c$ flows through a resistor R, according to the voltage calculation formula U = R * I, the voltage on the resistor will change greatly. We take out the voltage on the resistor and get the amplified voltage signal.

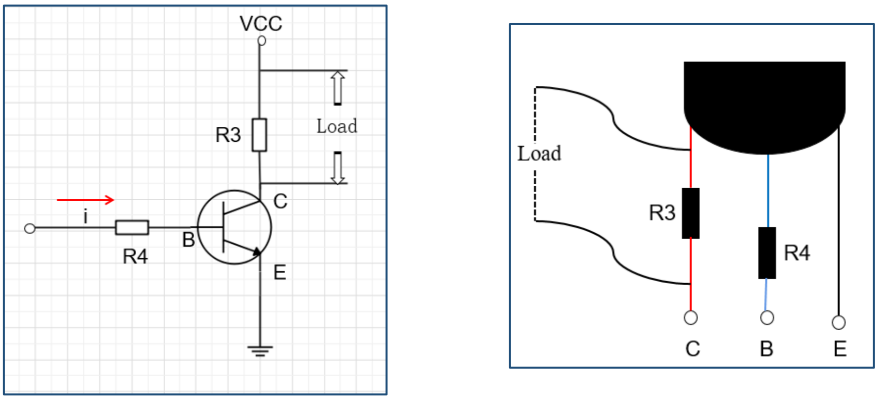



Figure 7 The wire connection of triode, R3=1k, R4=510Ω.

### 3.4 Pulse-Width Modulation (PWM) Signal Generation

The duty cycle of a pulsing wave is the percentage duration for which the pulse is 'on'. Consider a pulsing wave $V = V(t)$ with duty cycle $D$ and time period $T$ seconds. Using mean value theorem, the average value of this waveform over one period is:

$$\bar{V} = \frac{1}{T}\int_0^T V(t)dt$$

If the pulse wave has a maximum value $V_{max}$ for $DT$ seconds, and minimum value of $V_{min}$ for (1 - $D$)$T$ seconds, the average value from above becomes:

$$\bar{V} = DV_{\max} + (1 - D)V_{min}$$

In the case of the Elvis III workbench, the maximum voltage $V_{max}$ is 5 V and the minimum voltage $V_{min}$ is 0 V. Thus, the average motor voltage is

$$\bar{V} = 5D$$

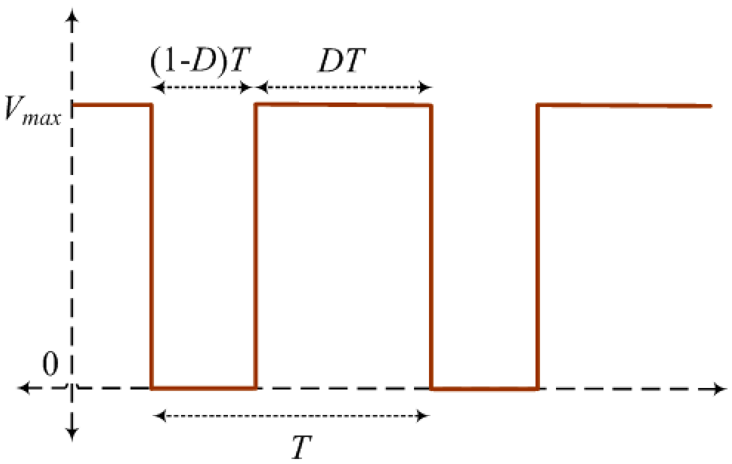



Figure 8 PWM pulse waveform

## 4. Project Guidelines

### Task 1: Temperature Sensor Data Acquisition

For the task 1, the PT 100 temperature sensor is used to acquire the temperature of hot water. Firstly, we need to create the hardware connection between the temperature sensor and the Elvis III workbench. Make the connections between the sensors and signal converters as displayed in Figure 9. Then connect the out pin of the temperature signal converter to one of the analog input ports of the NI ELVIS III Prototyping Board.

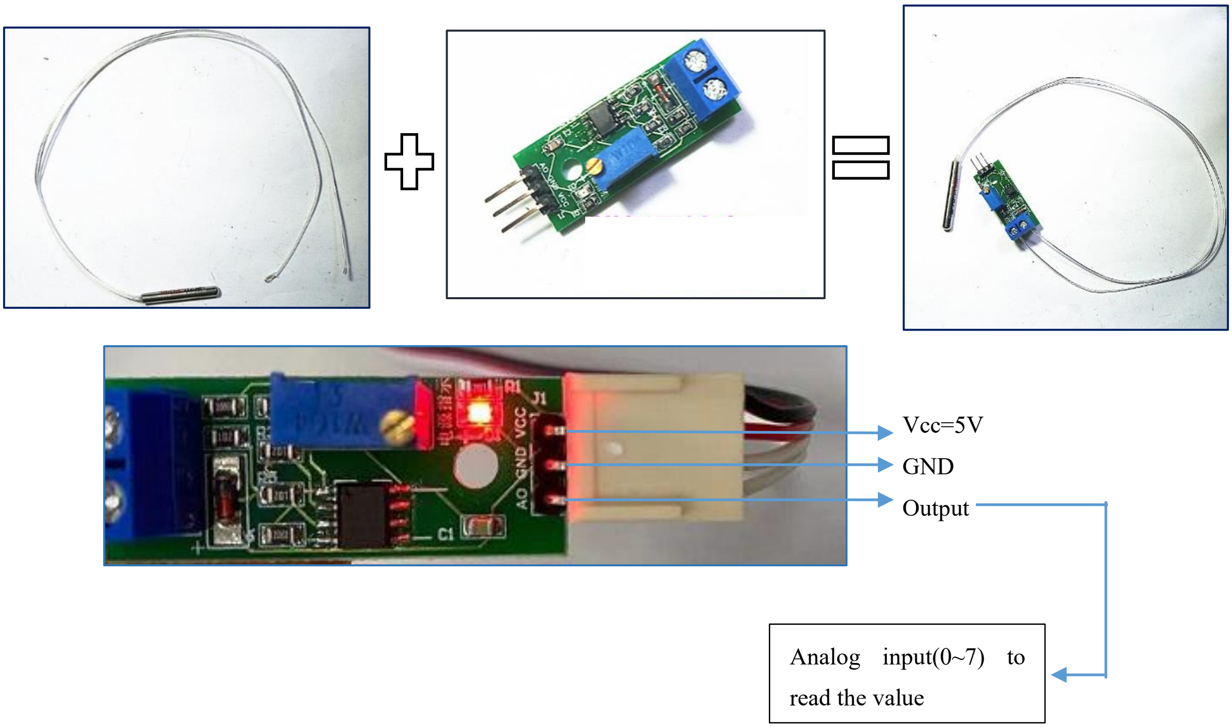
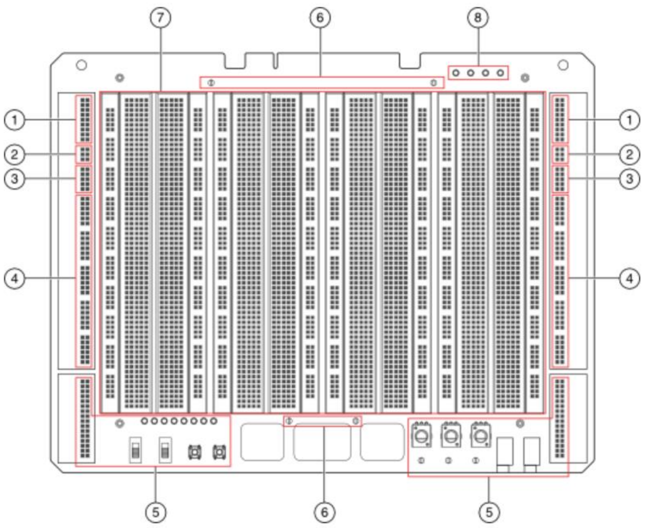



Figure 9 Temperature sensor connection

The available I/Os for the NI ELVIS III prototyping board via breadboard connectors, as well as additional user peripherals commonly used are displayed in Figure 10.



1. Analog Input
2. Analog Output
3. Fixed User Power Supplies
4. Digital I/O
5. User Peripherals
6. Digital Ground
7. Central Build Area (breadboard)
8. Fixed User Power Supplies LEDs

Figure 10 NI ELVIS III prototyping board

After you finish the hardware connection, the LabVIEW software is needed to acquire the temperature data from the PT100. We will use the Analog Input Express VI to serve this purpose. You can find this VI by following the procedure shown in Figure 11. Configure the VI to match the analog port on ELVIS III prototyping board, then leave the rest parameter as default.

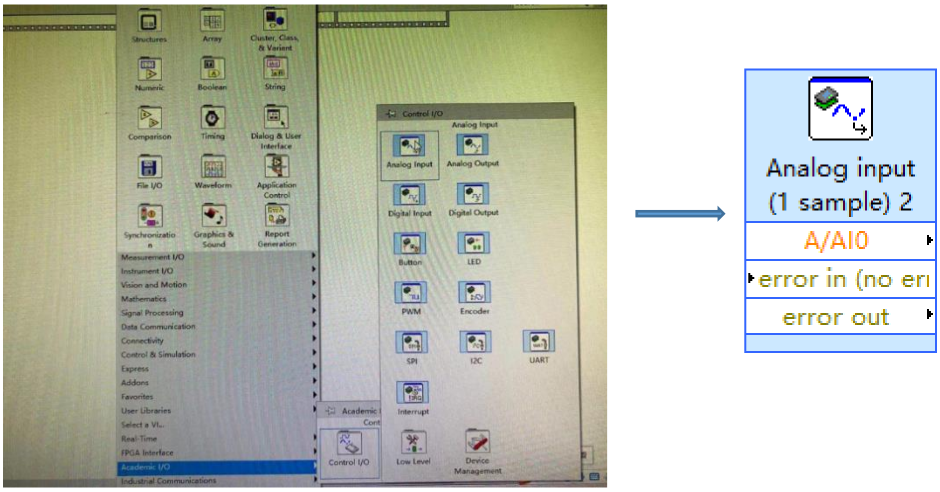



Figure 11 Analog input express VI

**Please note we are interfacing the Elvis III workbench hardware. The LabVIEW program should be built using the NI Elvis III Project. If you are not sure about where to find this, please consult TA before you proceed.**

**Task 2: Temperature Sensor Calibration**

Next, utilize the glass thermometer to calibrate the temperature-voltage relationship, as shown in Figure 12. Fit a calibration equation to the temperature sensor and use this equation for subsequent tasks.

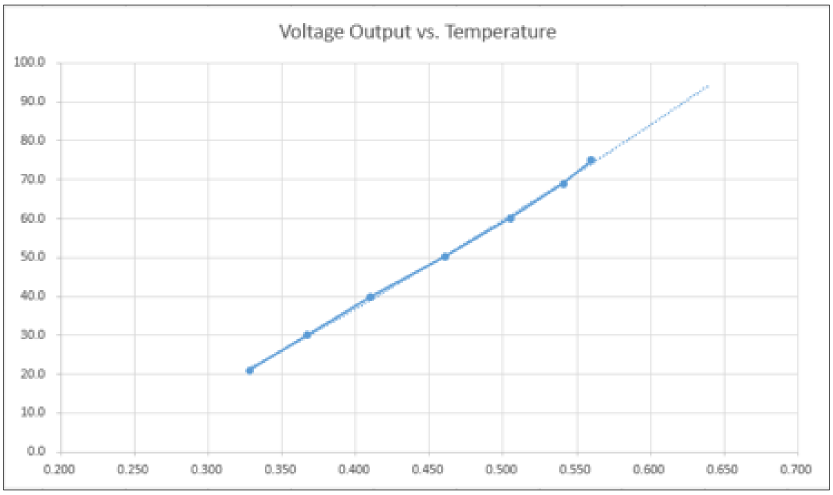



Figure 12 PT100 calibration

**Task 3: Infrared Sensor Data Acquisition**

For the task 2, the infrared sensor is used to detect the presence of human being. Make the hardware connections with dubont wire as shown in Figure 13. Build the LabVIEW software with the Analog input express VI which is introduced in Task 1 to read the output voltage of the infrared sensor. Test the function of the sensor and the program with your hand or other object.

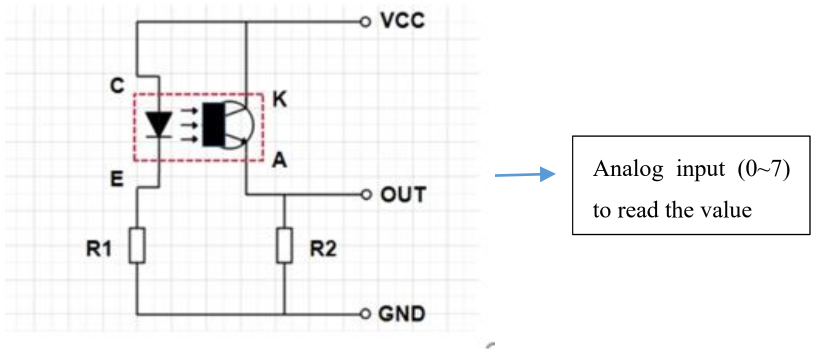



Figure 13 Infrared sensor hardware connection

**Task 4: Motor Speed Control with PWM Signal Generation**

Since the voltage from the I/O port of the Elvis III workbench is not enough to drive the DC motor, here we make a drive circuit using the Triode. With the variation of the duty cycle for the PWM signal, the output voltage to the DC motor can be adjusted, thus adjusting the motor speed. Make the connections among the triode, DC motor and NI ELVIS III prototyping board as shown in Figure 14.

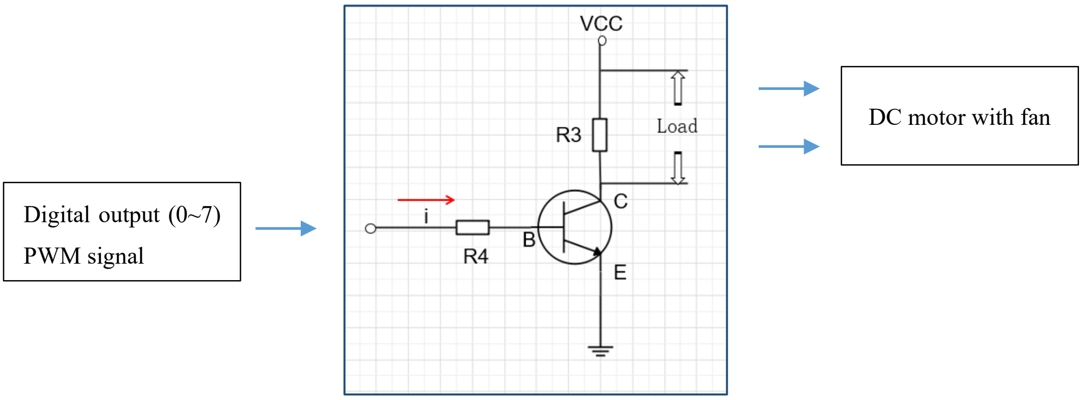



Figure 14 Triode with DC motor connection

Build a LabVIEW program using the PWM Express VI (Figure 15) to output control signal to the triode. Configure the channel number to the digital output channel which matches your hardware connection. Set the "frequency" as constant, 1000Hz and leave the other parameters unchanged. Use a numeric "Slide" control with the scale range from 0 to 1 to test the functionality of the motor speed control module.

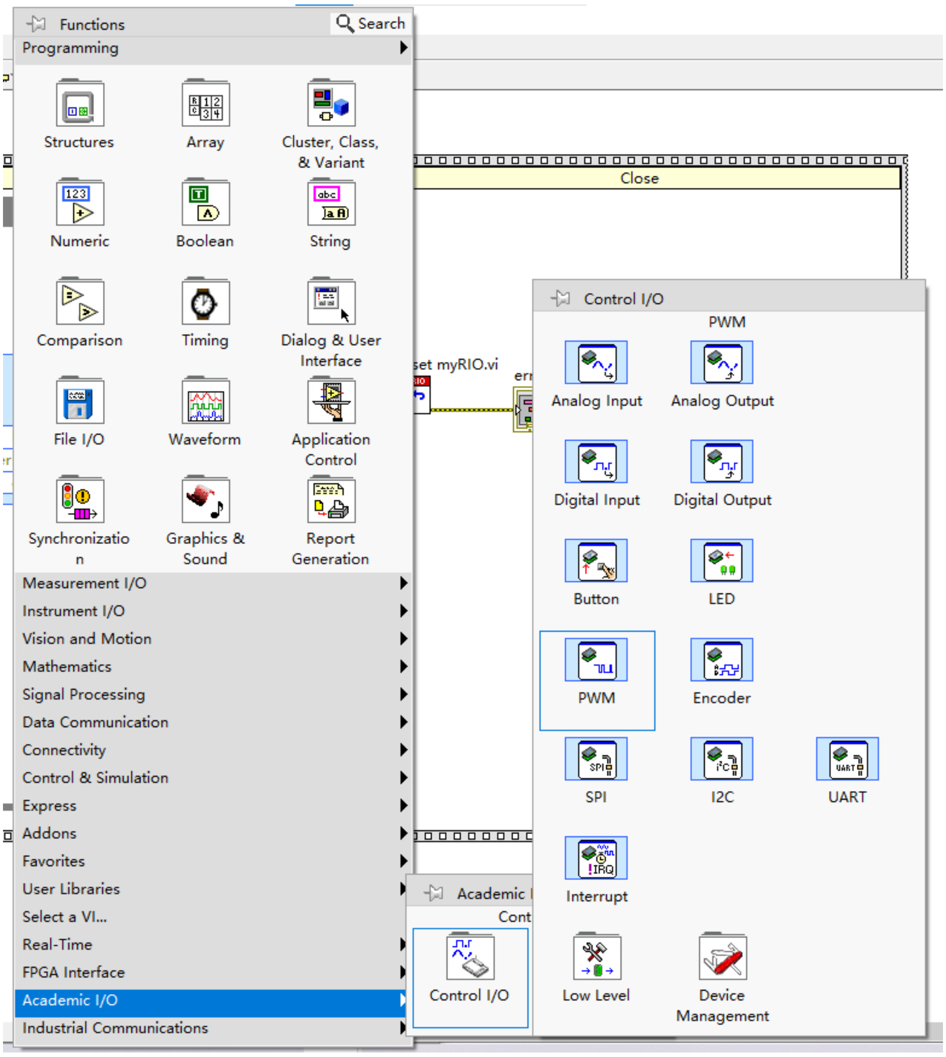



Figure 15 PWM express VI

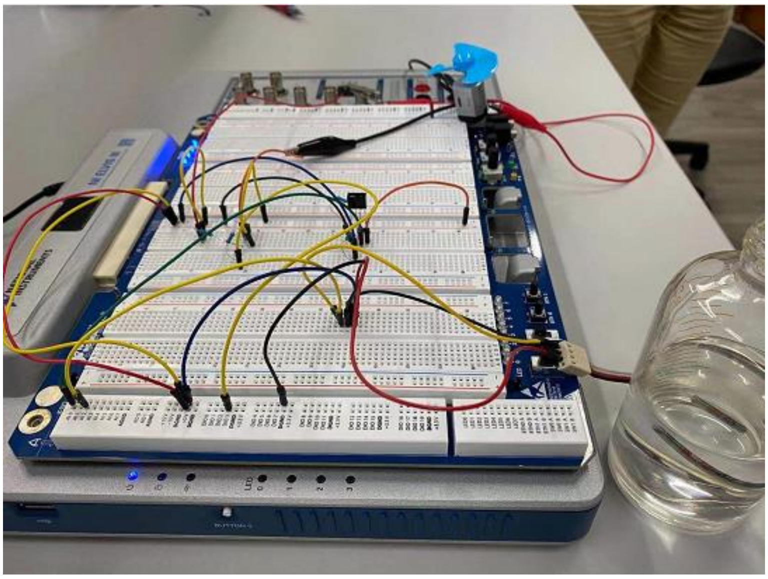


Figure 16 Temperature control system hardware connections

**Task 5: System Integration**

Finally, you will need to integrate all the components introduced in the previous four tasks into one system, including both hardware and software. An example of the hardware connections is shown in Figure 16. Then construct the LabVIEW program to achieve the following functions:

1) (20%) Coolant temperature measurement using PT100 with calibration equation
2) (10%) Human presence detection with infrared photoelectric sensor
3) (20%) Motor speed adjustment with PWM signal
4) (25%) Motor speed control with the change of the thermocouple temperature reading, i.e. increasing the motor speed with the increase of the detected temperature. Turns on the motor when the temperature is 8°C above the room temperature (25°C) and the motor reaches the maximum speed at 45°C.
5) (25%) Maximum motor speed in the presence of human operator regardless of the temperature sensor.

**The demo will be graded based on the weights associated with each function**

**At the end of this project, please submit a full lab report which includes the following parts:**

**Objective (5%)**

**Theory (20%)**

Resistance Temperature Detector
Infrared Photoelectric Sensor
Triode
Pulse-Width Modulation

**Procedure (20%)**

Temperature Data Measurement
Human Presence Detection
Motor Speed Adjustment

**Summary of Results (20%)**

Temperature Sensor Calibration
Motor Speed Control with Temperature and Human Presence

**Conclusion, Format, Organization, and Writing (15%)**

**Discussion (20%)**