
Make:
Sensors
Projects and Experiments to Measure the World with Arduino and Raspberry Pi
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6. Distance

Contents

How far is it ?

- An ultrasonic distance sensor is one of the most popular sensors in the embedded courses we teach.
- A robot must know when an obstacle is near if it is to navigate around it.
- And isn’t it more convenient to just wave your hand in the air instead of clicking a physical button?
- A burglar alarm can detect an intruder by noticing change in distance or heat pattern. Your home, office, or school probably has an alarm like that.

How far is it ?

- **The two most common ways to measure distance** are sound echoes and light reflection.
- To avoid annoying people with constant beeping and blinking, the sound frequency is usually so high that humans can’t hear it, and the light frequency is so high humans can’t see it.
- The high-frequency sound is ultrasonic, and the high-frequency light is infrared.

How far is it ?

- An ultrasonic sensor can provide exact distance readings.
  - For example, it could tell you that the distance to an object is 36 cm.
- To detect the proximity of humans and other living things, sensors can detect the heat they radiate. This lets you detect the presence of hot things in the measured area, but not their exact distance.
  - There are many ways for heat to move: conduction, convection, and radiation.
  - example： A passive infrared sensor measures radiated heat in the form of infrared light.

How far is it ?

- In contrast to passive infrared sensors, an active infrared distance sensor sends invisible light and tests whether it reflects back.
- It can tell if something is closer than a given distance.
  - For example, an active infrared sensor could tell you that there is an object closer than 30 cm, but it wouldn't know if it's 5 cm or 29 cm away.
  - As a rare exception, some sensors estimate distance from reflected infrared light.

How far is it ?

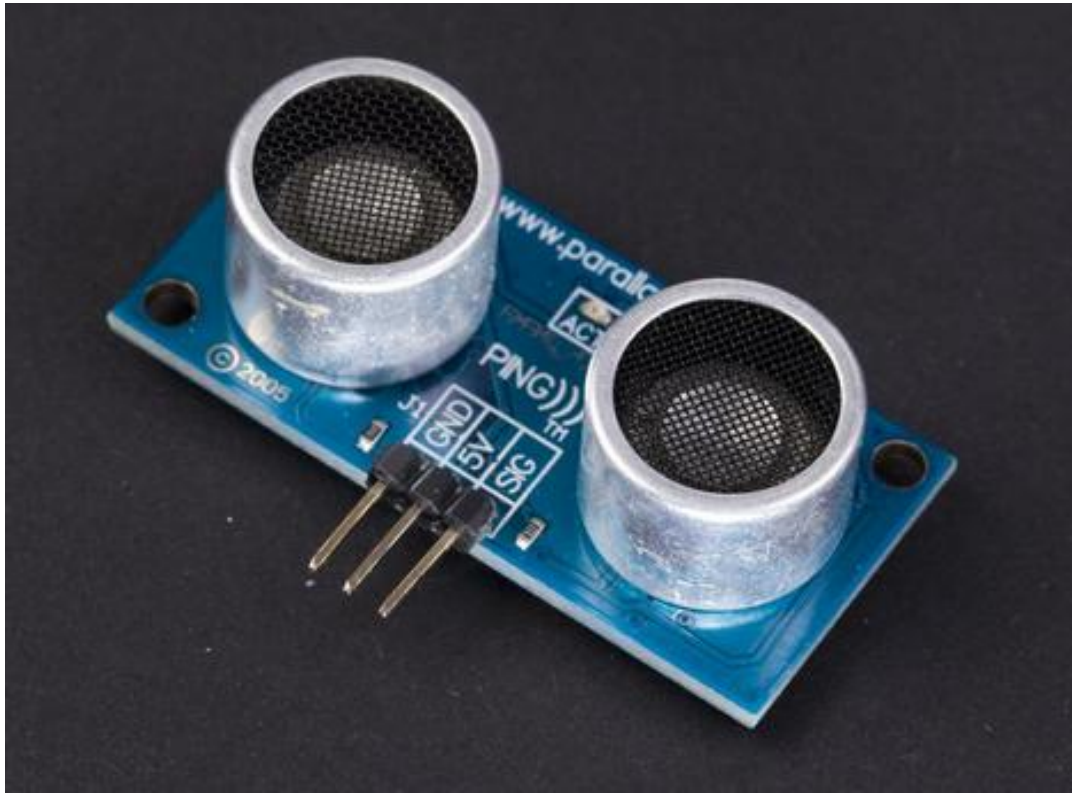
- Long-distance range finders can use a laser beam to measure distance.
- Most of them are based on factoring in the speed of light and the time it takes for a beam to be reflected.
- Because light is very fast, the circuit must be able to do very precise timing. This makes them quite expensive.
- They are far less commonly used for prototyping with Arduino or Raspberry Pi than sound and IR.

Contents

Experiment: Measure Distance with Ultrasonic Sound (PING)

- Nowadays, there are many cheap ultrasonic sensors inspired by the Ping sensor from Parallax.

  - Ping, 1, 2, 3… pong. An ultrasonic sensor sends a sound, and then measures the time for the echo to return.
  - Because you know that sound moves at about 330 meters per second, your program can calculate the distance.

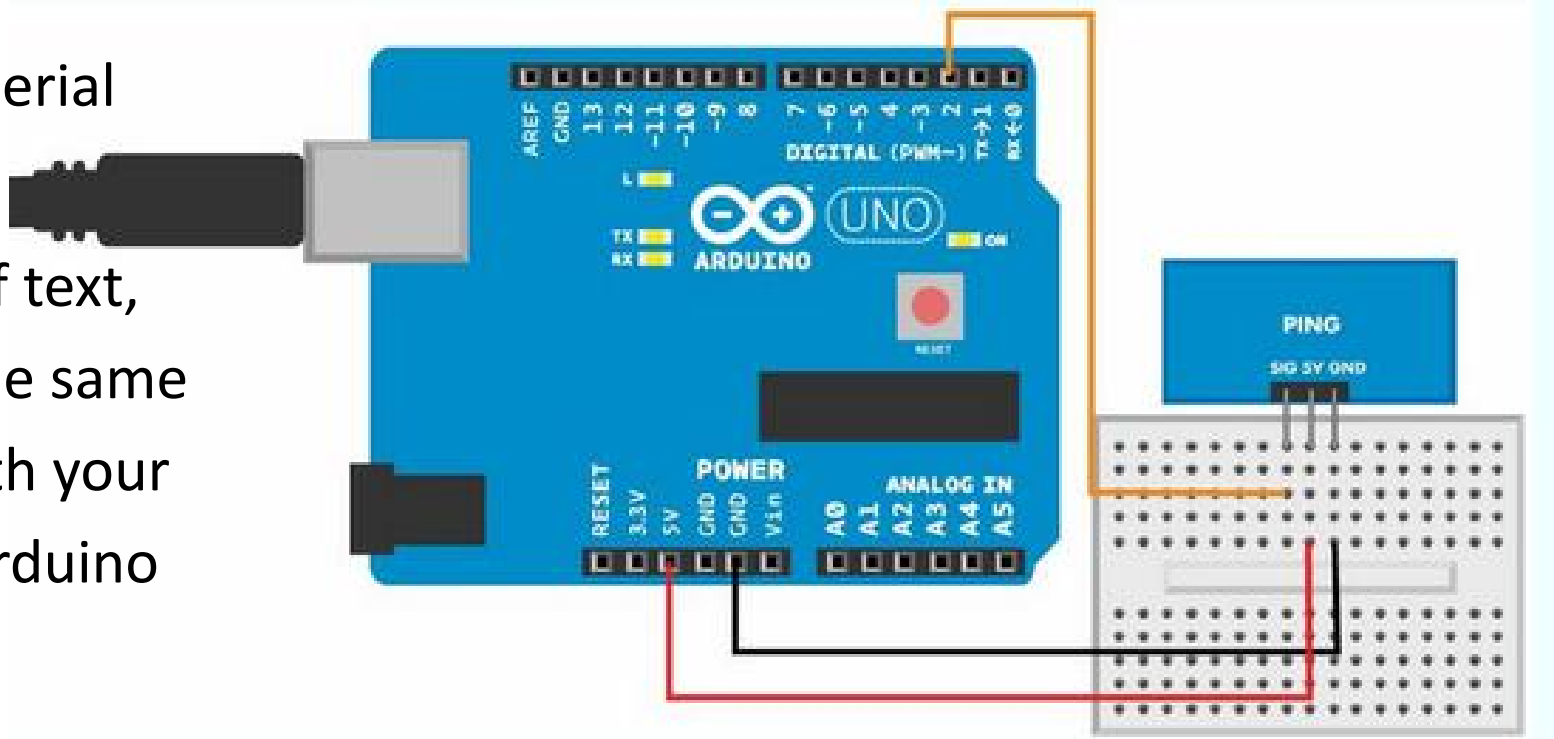


Experiment: Measure Distance with Ultrasonic Sound (PING)

- Ping is an older, popular sensor by Parallax. Compared with the alternatives, it's a bit expensive.
- If you need a lot of distance sensors, you might want something cheaper.
- The similar HC-SR04 costs only a couple of dollars, and the only difference in configuration between the Ping and HC-SR04 is one pin.
  - HC-SR04 uses one pin to trigger sending a pulse and another to read the echo.
  - The sensors have almost identical code.

Ping Code and Connections for Arduino

- Figure 2 shows the wiring diagram for the Ping sensor and Arduino.
- Build the circuit, and then compile and upload the code using the Arduino IDE.
  - To see the readings, use the serial monitor .
  - If you get gibberish instead of text, make sure that you specify the same speed (bit/s or “baud”) in both your code (Serial.begin) and the Arduino Serial Monitor.



2. Ping sensor circuit for Arduino

Ping Code and Connections for Arduino

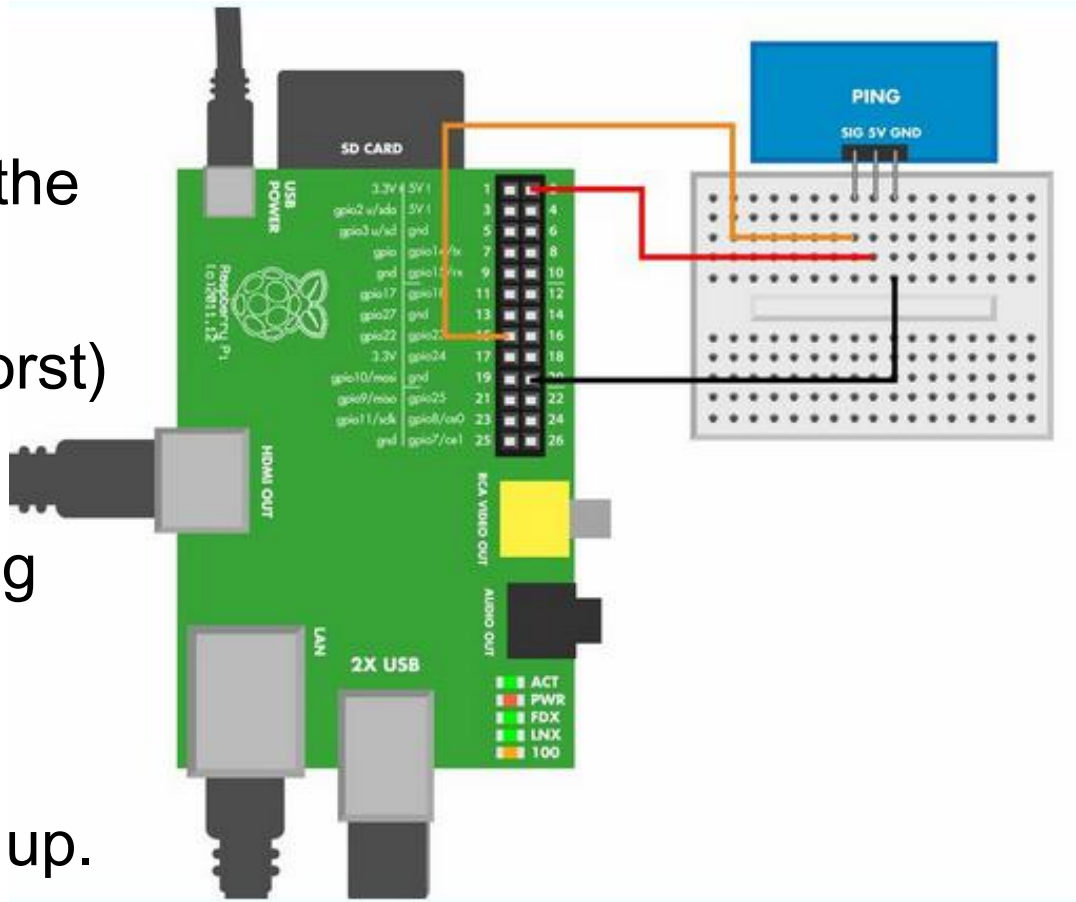
Example 1. distance_ping.ino

```
// distance_ping.ino - distance using ultrasonic ping sensor
// (c) BotBook.com - Karvinen, Karvinen, Valtokari

int pingPin = 2;
float v=331.5+0.6*20; // ❶ m/s
void setup(){
        Serial.begin(115200);
}

void loop(){
        int d=distanceCm();
        Serial.println(d, DEC);  //❽
        delay(200);          // ❾ ms
}

float distanceCm(){  // send sound pulse
        pinMode(pingPin, OUTPUT);          //❷
        digitalWrite(pingPin, LOW);
        delayMicroseconds(3);              //❸
        digitalWrite(pingPin, HIGH);
        delayMicroseconds(5);              //❹
        digitalWrite(pingPin, LOW);
        // listen for echo
        pinMode(pingPin, INPUT);
        float tUs = pulseIn(pingPin, HIGH); // ❺ us
        float t = tUs / 1000.0 / 1000.0 / 2;  // ❻ s
        float d = t*v; // m                  // ❼
        return d*100; // cm
}
```

Ping Code and Connections for Raspberry Pi

- Build the circuit for Ping in Raspberry Pi as shown in Figure 3-3, and then run the code listed in Example 2.

  - Be careful when connecting anything to the GPIO header. A wrong connection can easily damage (at best) one pin or (at worst) your whole Raspberry Pi.
  - You can avoid problems by disconnecting power when making or changing connections, and double-checking connections to the pins before powering up.



-3. Ping sensor circuit for Raspberry Pi

Ping Code and Connections for Raspberry Pi

Example 2. distance_ping.py

```
# distance_ping.py - print distance
# (c) BotBook.com - Karvinen, Karvinen, Valtokari

import time                    ❶
import botbook_gpio as gpio    ❷
```

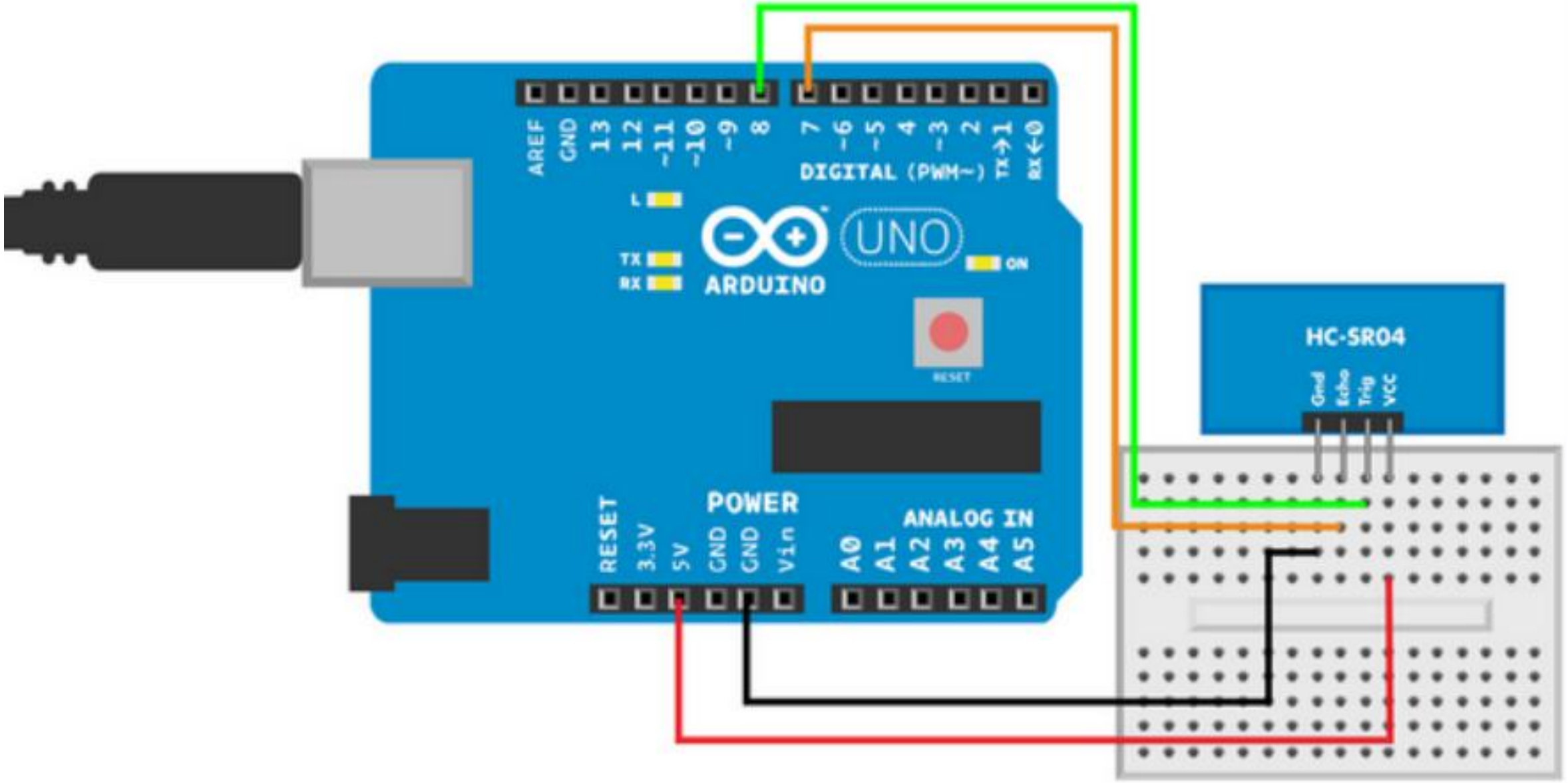
```
def readDistanceCm():
        sigPin=22
        v=(331.5+0.6*20)
        gpio.interruptMode(sigPin, "both") ❸
        gpio.mode(sigPin, "out")           ❹
        gpio.write(sigPin, gpio.LOW)       ❺
        time.sleep(0.5) # s
        gpio.write(sigPin, gpio.HIGH)      ❻
        time.sleep(1/1000.0/1000.0)        ❼
        gpio.mode(sigPin, "in")            ❽
        #Read high pulse width
        t = gpio.pulseInHigh(sigPin)       # s ❾
        d = t*v
        d = d/2                                ❿
        return d*100    # cm
```

```
def main():
        d = readDistanceCm()
        print "Distance is %.2f cm" % d
        time.sleep(0.5)

if __name__ == "__main__":
        main()
```

HC-SR04 Ultrasonic Sensor

- The HC-SR04 is just like the Ping but is available at a fraction of the cost.
- The code for this sensor is almost the same as Ping code, except the HC-SR04 uses separate pins for triggering the sound and listening for the echo.
- For detailed code explanations, see Ping Code and Connections for Arduino and Ping Code and Connections for Raspberry Pi;
- the explanations in this section will focus on the differences.

HC-SR04 Code and Connection for Arduino



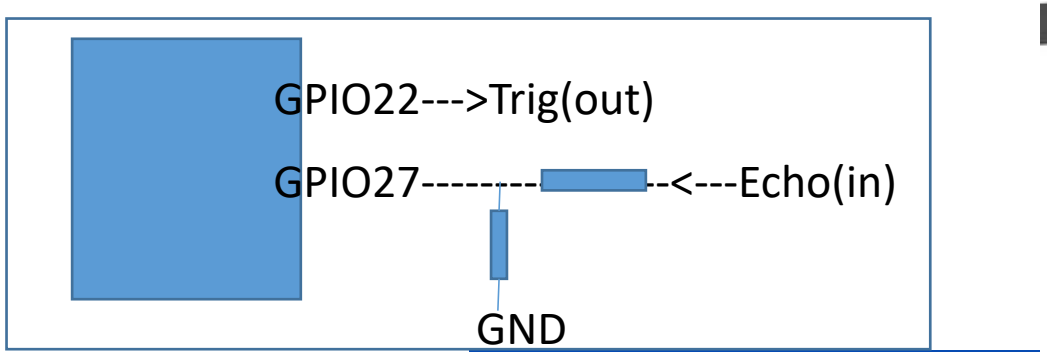
HC-SR04 Code and Connection for Arduino

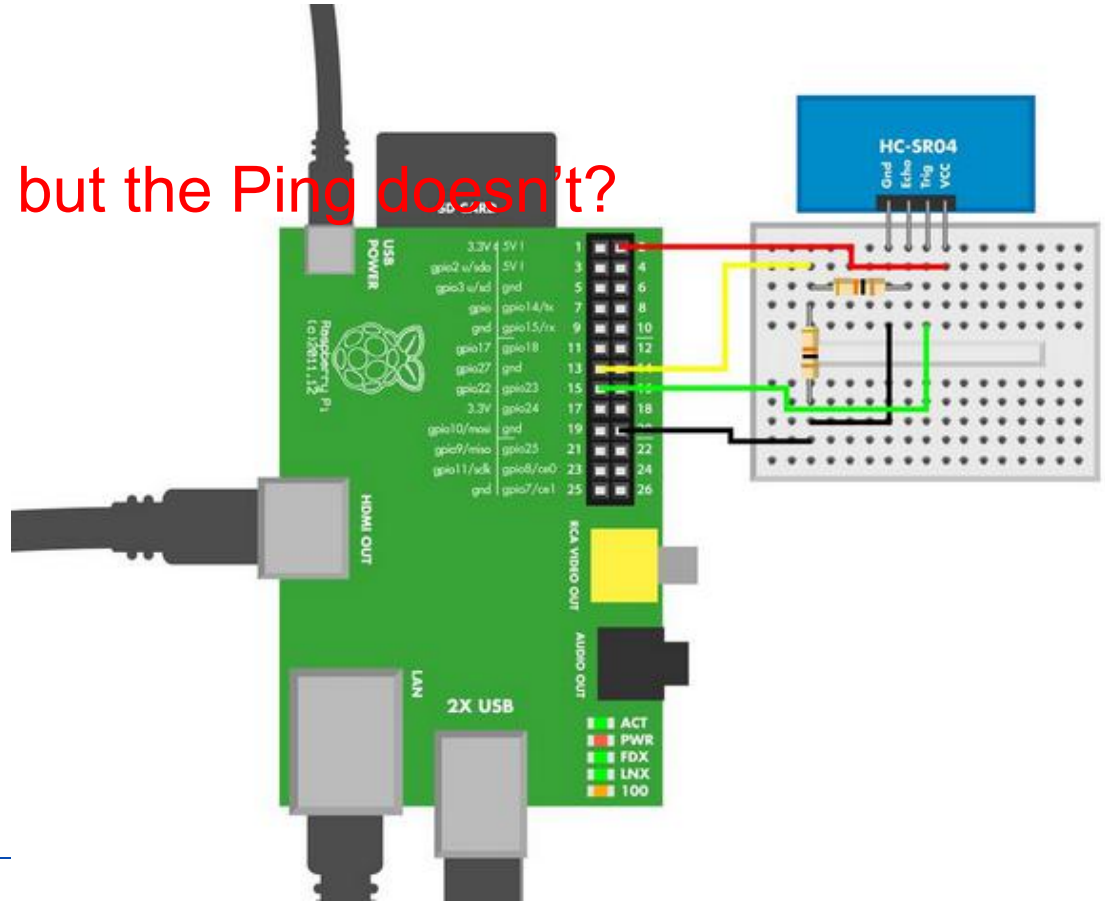
Example 3. hc-sr04.ino

```
// hc_sr04.ino - print distance to serial
// (c) BotBook.com - Karvinen, Karvinen, Valtokari
int trigPin = 8;
int echoPin = 7;
float v=331.5+0.6*20;       // m/s

void setup(){
        Serial.begin(115200);
        pinMode(trigPin, OUTPUT);    ❶
        pinMode(echoPin, INPUT);     ❷
}

void loop() {     ❸
        int d=distanceM();
        Serial.println(d, DEC);
        delay(200); // ms
}

float distanceM(){
// send sound pulse
        digitalWrite(trigPin, LOW);
        delayMicroseconds(3);
        digitalWrite(trigPin, HIGH);
        delayMicroseconds(5);
        digitalWrite(trigPin, LOW);
// listen for echo
        float tUs = pulseIn(echoPin, HIGH);          //us
        float t = tUs / 1000.0 / 1000.0 / 2;         // s
        float d = t*v; // m
        return d*100; // cm
}
```

HC-SR04 Code and Connections for Raspberry Pi

- Build the circuit (Figure 6) and upload the code shown in Example 4.
- Take notice that in addition to jumper wires, you also need to add two 10 kOhm resistors
- Why does the HC-SR04 need a resistor, but the Ping doesn't?
  - Echo +5v——Pi +3.3v
- The code is very similar to Ping.





HC-SR04 Code and Connections for Raspberry Pi

Example 4. hc-sr04.py

```
# hc-sr04.py - print distance to object in cm
# (c) BotBook.com - Karvinen, Karvinen, Valtokar

import time
import botbook_gpio as gpio
```

```
def readDistanceCm():
        triggerPin = 22
        echoPin = 27
        v=(331.5+0.6*20) # m/s
        gpio.mode(triggerPin, "out")
        gpio.mode(echoPin, "in")
        gpio.interruptMode(echoPin, "both")
        gpio.write(triggerPin, gpio.LOW)
        time.sleep(0.5)
        gpio.write(triggerPin, gpio.HIGH)
        time.sleep(1/1000.0/1000.0)
        gpio.write(triggerPin, gpio.LOW)
        t = gpio.pulseInHigh(echoPin) # s
        d = t*v /2
        return d*100    # cm
```

```
def main():
        d = readDistanceCm()
        print "Distance is %.2f cm" % d
        time.sleep(0.5)
if __name__ == "__main__":      main()
```

Echo Calculations Explained

$d = t*v$

- Sound moves faster when it's warm. Sound is the vibration of air, and the vibrations move better if air molecules are already vibrating with heat.
- If you live in a warm place, we envy you because you probably need less calibration.
- In the north of Finland, it might be +22 C inside and -40 C outside, resulting in over 60 C difference in temperature. A change this big will clearly affect measurements. Temperature (T) affects the speed of sound (r) according to the formula

  $v = (331.3+0.606*T)$ m/s

- This formula gives the speed of sound in practice (343 m/s at 20 C).

Contents

Environment Experiment: Invisible Objects

Figure 3-7. Testing ping sensor with a soft object

Environment Experiment: Invisible Objects

- 隐形战斗机是通过机身涂上一层高效吸收电波的物质，造成雷达无法追踪的效果；
- 还有一种要比涂上一层高效吸收电波的物质还要好的隐形办法，等离子（还在研制）
- 但是只靠涂吸收电波的物质也是达不到很好的效果的，还要在飞机的气动布局上做修改，要使飞机的平面反射面积尽量的小，同时还要对发动机的红外辐射做简化处理
- 隐形飞机要从很多方面下手才能达到隐形的效果。

Contents

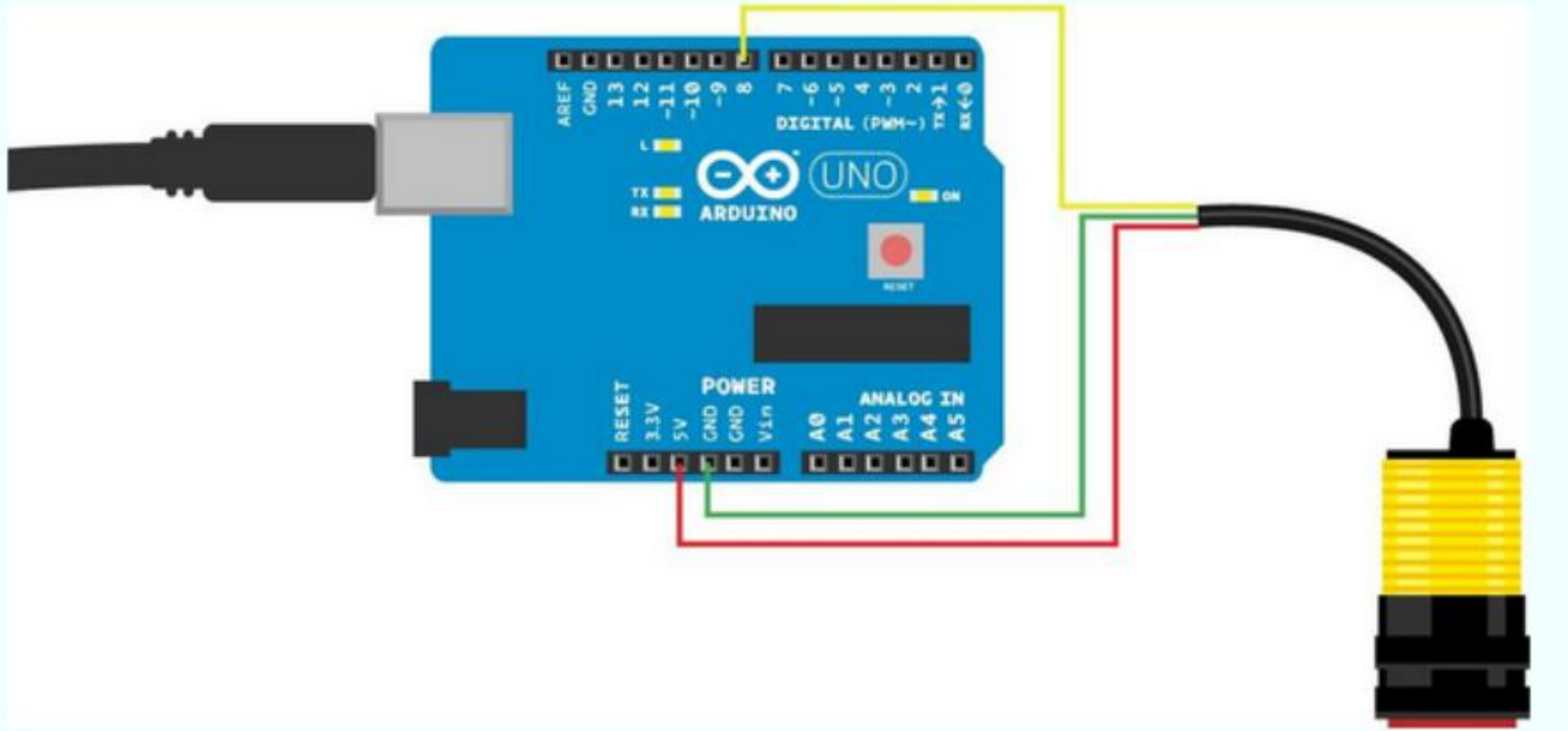
Experiment: Detect Obstacles With Infrared (IR Distance Sensor)

- An infrared switch (Figure 8) is more reliable than an ultrasonic one, but less versatile.
- You can’t fool it as easily as you fooled ultrasound in the experiment you did earlier.
- But an infrared switch can tell you only if there is something present, not the distance to it.
- And because the sun is a great big source of infrared light, it’s strong enough to blind an infrared switch.

Experiment: Detect Obstacles With Infrared (IR Distance Sensor)

- 可以调整传感器检测障碍物的距离。

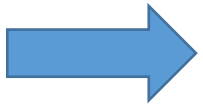
IR Switch Code and Connections for Arduino



IR Switch Code and Connections for Arduino

Example 5. adjustable_infrared_sensor_switch.ino

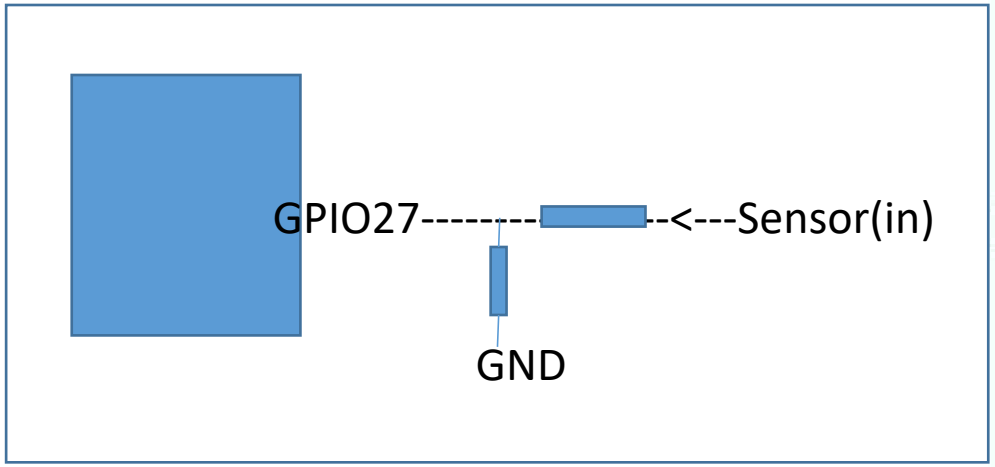
```
// adjustable_infrared_sensor_switch.ino - print detection to serial and light LED.
// (c) BotBook.com - Karvinen, Karvinen, Valtokari
const int sensorPin = 8;
const int ledPin = 13;

int switchState = 1;                    //传感器数值，1没检测到
void setup() {
        Serial.begin(115200);
        pinMode(sensorPin, INPUT);
        pinMode(ledPin, OUTPUT);
}
```

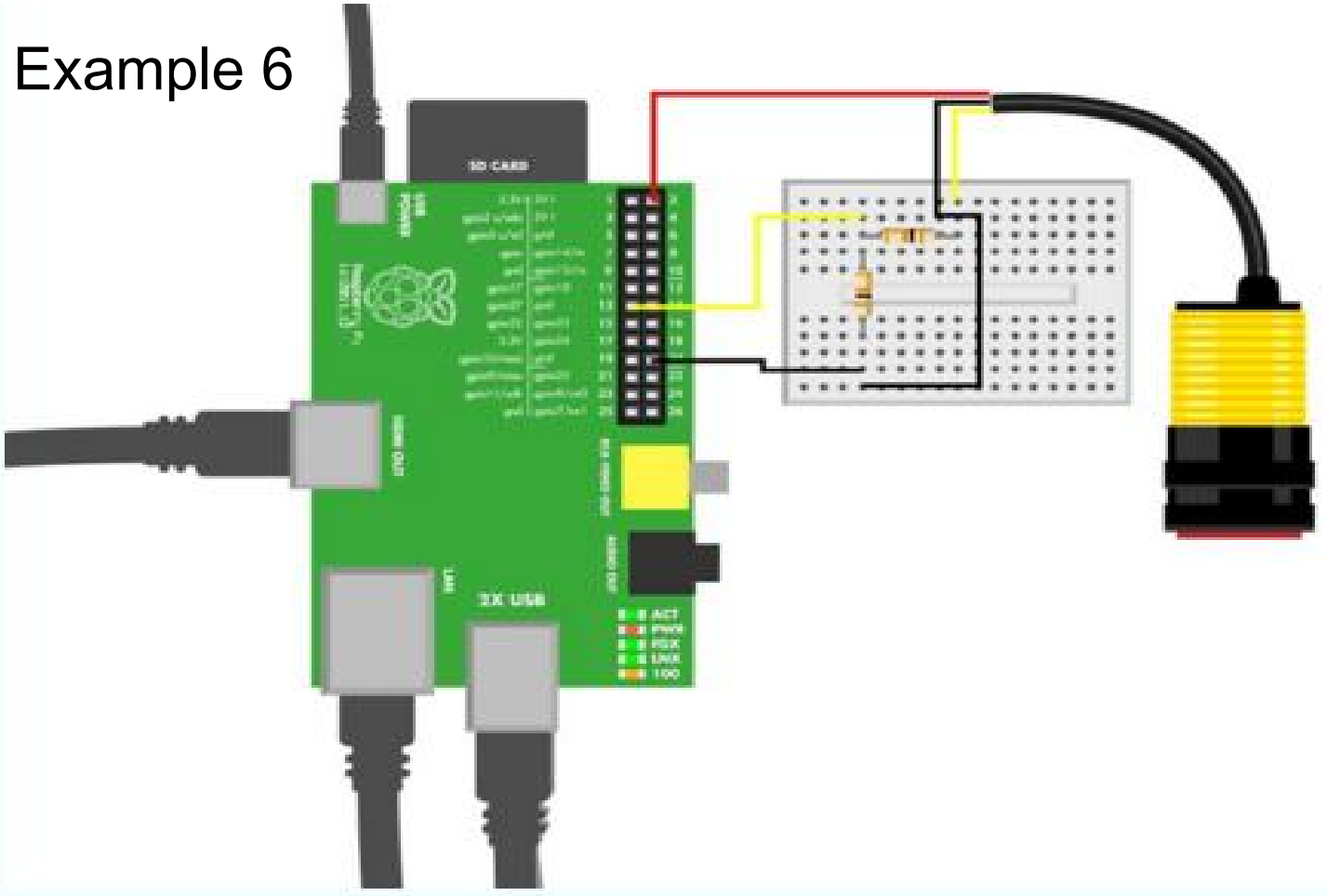


```
void loop() {
        switchState = digitalRead(sensorPin);
        Serial.println(switchState);
        if(switchState == 0) {
                digitalWrite(ledPin, HIGH);
                Serial.println("Object detected!");
        } else {
                digitalWrite(ledPin, LOW);
        }
        delay(10); // ms
}
```

IR Switch Code and Connections for Raspberry Pi

- Figure 11 shows the wiring diagram for Raspberry Pi and the switch. The corresponding Python code is in Example 6





IR Switch Code and Connections for Raspberry Pi

Example 6. adjustable-infrared-sensor-switch.py

```
# adjustable-infrared-sensor-switch.py - read infrared switch
# (c) BotBook.com - Karvinen, Karvinen, Valtokari
import time
import botbook_gpio as gpio
def main():
        switchPin = 27
        gpio.mode(switchPin, "in")
        x = gpio.read(switchPin)
        if( x == gpio.LOW ):
                print "Something is inside detection range"
        else:
                print "There is nothing inside detection range“
        time.sleep(0.1)

if __name__ == "__main__":
    main()
```

Contents

Environment Experiment: How to See Infrared

- You could use night-vision goggles（夜视仪）
- You could use any cheap digital camera（便宜的数码相机）
- Try looking at an IR sensor through your smartphone’s camera. Be aware that some cameras have strong infrared filters that prevent unwanted wavelength from being part of your photos

Contents

Experiment: Follow Movement with Infrared (IR Compound Eye)

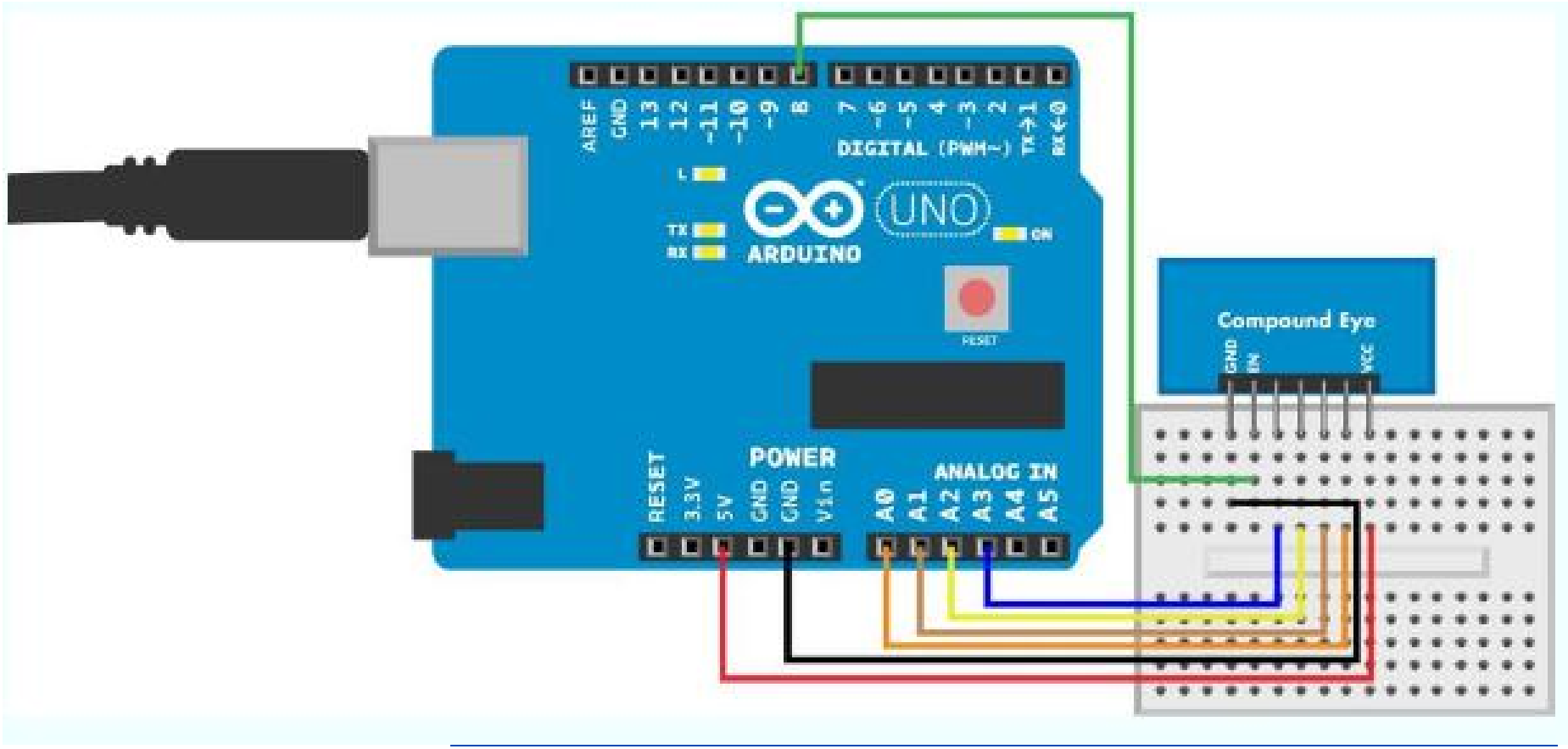
- A compound eye has many infrared-sensitive transistors and LEDs. It can track movement within 20 cm. Even though it's one sensor, each of the infrared (IR) light-sensitive transistors can be read separately. Ambient light correction is done by turning off the IR LEDs and comparing values.
- If you want to improve readings from your compound eye, you must calibrate it.

Figure 3-14. Image of IR Compound Eye

产品应用

Compound Eye Code and Connection for Arduino

- Figure 16 shows the wiring diagram for Arduino and the compound eye. The Arduino sketch is shown in Example 7.



Compound Eye Code and Connection for Arduino

Example 7. compound_eye.ino

```
// compound_eye.ino - print distance and direction values to serial
// (c) BotBook.com - Karvinen, Karvinen, Valtokari

const int irEnablePin = 8;
const int irUpPin = 0;
const int irDownPin = 2;
const int irLeftPin = 1;
const int irRightPin = 3;

int distance = 0;
int irUpValue = 0;
int irDownValue = 0;
int irLeftValue = 0;
int irRightValue = 0;
```

声明引脚为const，就无法在程序中修改它们的值，就算不小心进行了赋值操作，那也会在验证或上传程序时编译器给出错误信息。

将传感器的读取数值存储在全局变量中，可以被所有的函数使用，在C或C++中，声明变量并初始化，是一个很好的习惯

Compound Eye Code and Connection for Arduino

```
void setup() {
        Serial.begin(115200);
        pinMode(irEnablePin, OUTPUT);
}
void loop() {
        readSensor();
        Serial.print("Values: ");
        Serial.print("irUpValue");        Serial.print(irUpValue);        Serial.print(",");
        Serial.print("irDownValue");      Serial.print(irDownValue);      Serial.print(",");
        Serial.print("irLeftValue");      Serial.print(irLeftValue);      Serial.print(",");
        Serial.print("irRightValue");     Serial.print(irRightValue);     Serial.print(",");
        Serial.print("distance");         Serial.println(distance);
        delay(100);
}
```

Compound Eye Code and Connection for Arduino

```
void readSensor() {
        digitalWrite(irEnablePin, HIGH); ❶ 打开红外线LED，照亮目标进行测量。等待输入稳定
        delay(5); // ms
        irUpValue = analogRead(irUpPin);
        irDownValue = analogRead(irDownPin);
        irLeftValue = analogRead(irLeftPin);
        irRightValue = analogRead(irRightPin);

        digitalWrite(irEnablePin, LOW);  ❷ 关闭红外线LED。现在所有检测到的光线都来自于周围环境。
        delay(5);
        int ambientLight ;                    ❸ 开始测量周围环境的光线（例如来自太阳的不可见红外线）
        ambientLight = analogRead(irUpPin);              irUpValue = irUpValue - ambientLight;    ❹
        ambientLight = analogRead(irDownPin);            irDownValue = irDownValue - ambientLight;
        ambientLight = analogRead(irLeftPin);            irLeftValue = irLeftValue - ambientLight;
        ambientLight = analogRead(irRightPin);           irRightValue = irRightValue - ambientLight;
        distance = (irUpValue+irDownValue+irLeftValue+irRightValue) / 4;   ❺
}
```

Compound Eye Code and Connections for Raspberry Pi

- The IR compound eye contains eight infrared-sensitive sensors, which are connected in pairs, so there is a total of four sensors you can read.
- Each IR sensor is read as an analog resistance sensor.
- The Raspberry Pi requires an external ADC (analog-to-digital converter) to read the IR sensors.
- One MCP3002 chip can read two analog inputs. Because we need to read four sensors, we use two MCP3002 chips.

Compound Eye Code and Connections for Raspberry Pi

- This circuit (shown in Figure 17) has many things in it, but the principle is simple: there are four analog resistance sensors, and you read them one by one. Build the circuit as shown, and then run the code shown in Example 8.

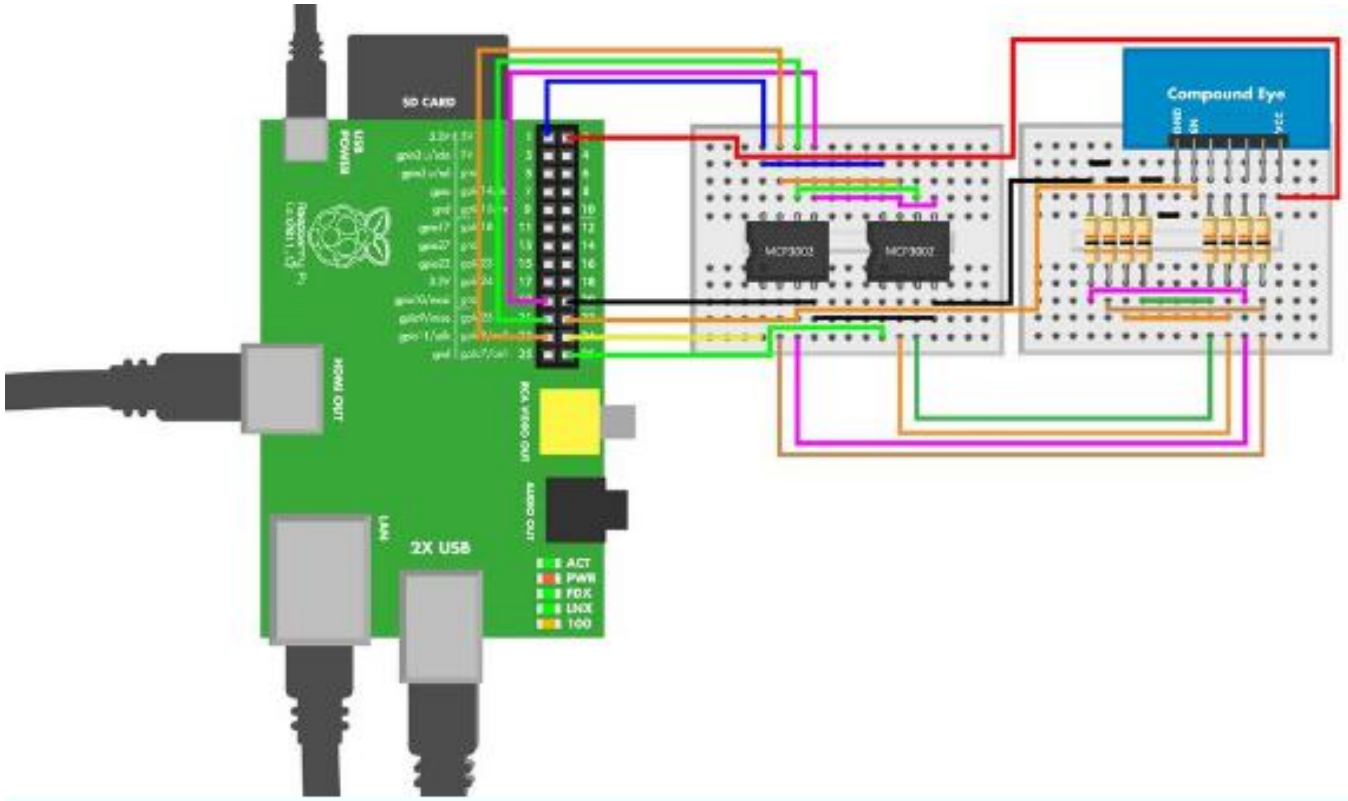
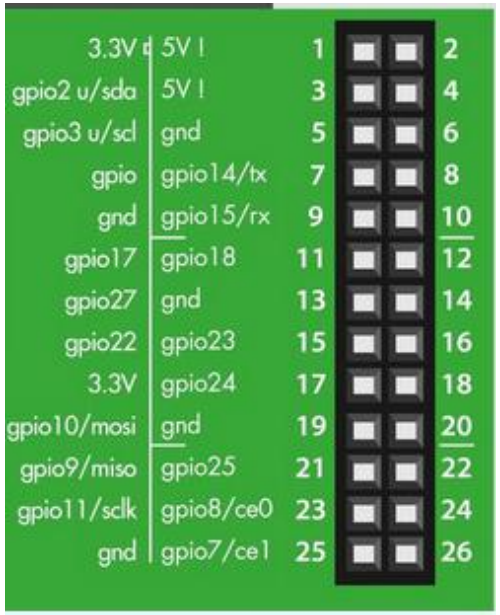
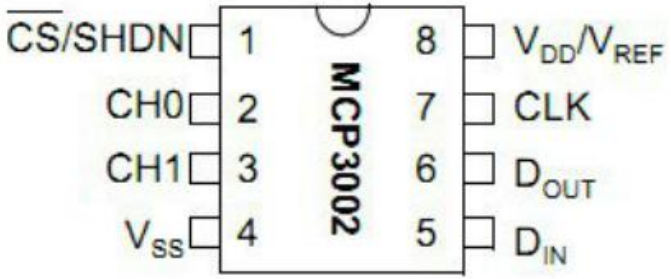


Figure 3-17. Compound eye connections on Raspberry Pi

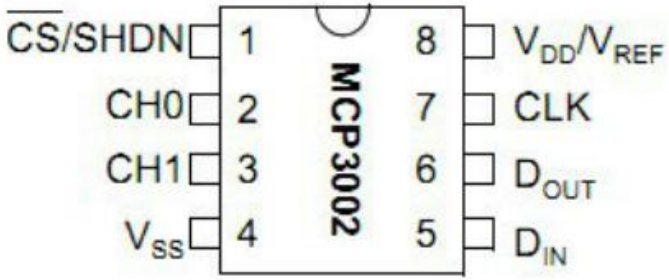


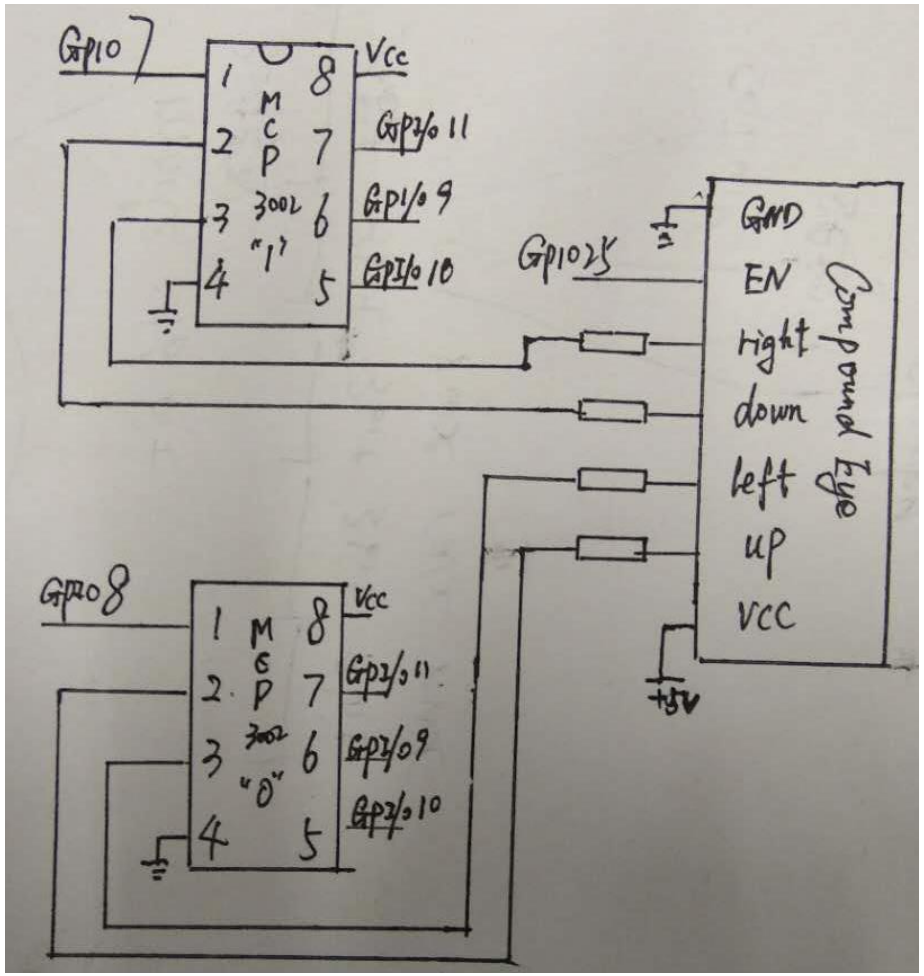


Compound Eye Code and Connections for Raspberry Pi

Example 3-8. compound_eye.py

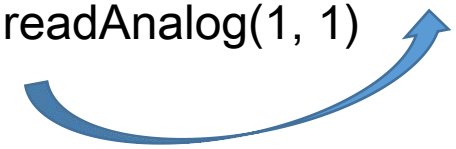
```
# compound_eye.py - read distance and direction.
# (c) BotBook.com - Karvinen, Karvinen, Valtokari

import time
import botbook_gpio as gpio
import botbook_mcp3002 as mcp
irUpValue = 0
irDownValue = 0
irLeftValue = 0
irRightValue = 0
distance = 0
```





Compound Eye Code and Connections for Raspberry Pi

```
def readCompoundEye():
        global irUpValue,irDownValue,irLeftValue,irRightValue,distance
        ledPin = 25
        gpio.mode(ledPin, "out")
        gpio.write(ledPin, gpio.HIGH)          #打开红外复眼传感器的红外线LED,照亮目标区域，便于测量
        time.sleep(0.05)   #Wait for sensors to get ready

        irUpValue = mcp.readAnalog(0, 0)
        irDownValue = mcp.readAnalog(1, 0)
        irLeftValue = mcp.readAnalog(0, 1)
        irRightValue = mcp.readAnalog(1, 1)
```



```
ambientLight = 0
gpio.write(ledPin, gpio.LOW)   #关闭红外线LED，消除环境光线影响
time.sleep(0.05)
ambientLight = mcp.readAnalog(0, 0)
irUpValue = irUpValue - ambientLight
ambientLight = mcp.readAnalog(1, 0)
irDownValue = irDownValue - ambientLight
ambientLight = mcp.readAnalog(0, 1)
irLeftValue = irLeftValue - ambientLight
ambientLight = mcp.readAnalog(1, 1)
irRightValue = irRightValue - ambientLight
distance = (irUpValue+irDownValue+irLeftValue+irRightValue)/4
```

```
readAnalog(device = 0,channel = 0)
```

Compound Eye Code and Connections for Raspberry Pi

```
def main():
        global irUpValue,irDownValue,irLeftValue,irRightValue,distance
        while True:     #大多数嵌入式设备都是让程序永远重复执行相同行为，用Control-C停止
                readCompoundEye()      #不需要返回值，因为修改了全局变量。
                                       #Python支持函数返回多个值，如a,b,c=foo();
                print "Values:"
                print "Up: %f" % irUpValue
                print "Down: %f" % irDownValue
                print "Left: %f" % irLeftValue
                print "Right: %f" % irRightValue
                print "Distance: %f" % distance
                time.sleep(0.5) # s     #
 if __name__ == "__main__":
        main()
```

INSTALLING SPIDEV

- The MCP3002 analog-to-digital converter uses the SPI protocol.
- SPI is quite a complicated protocol, but you can install the SpiDev library to handle the details.

- The SpiDev library is required by all code that uses *import spidev*. This includes the potentiometer code for Raspberry Pi, and every analog resistance sensor used in this book, because SpiDev is imported by botbook_mcp3002.

INSTALLING SPIDEV

- On your Raspberry Pi, open a terminal. First, install prerequisites:
  - $ sudo apt-get update
  - $ sudo apt-get -y install git python-dev
- Download the latest version of SpiDev from its version control site:
  - $ git clone https://github.com/doceme/py-spidev.git
  - $ cd py-spidev/
- And install it to your system:
  - $ sudo python setup.py install

INSTALLING SPIDEV

- Next, you need to enable the SPI module on the Raspberry Pi.
  - First, make sure it is not disabled.
    - Edit the file with the command *sudoedit /etc/modprobe.d/raspi-blacklist.conf* and delete this line: blacklist spi-bcm2708
    - Save the file: press Control-X, type y, and then press Enter or Return.
  - To allow access to SPI without root
    - $ sudo cp 99-spi.rules /etc/udev/rules.d/99-spi.rules
  - Reboot your Raspberry Pi
    - $ ls -l /dev/spi*

```
# /etc/udev/rules.d/99-spi.rules - SPI without root on Raspberry Pi
# Copyright 2013 http://BotBook.com

SUBSYSTEM=="spidev", MODE="0666"
```

Alternative Circuits for Raspberry Pi

- The Raspberry Pi circuit for IR compound eye is quite complicated.
- Even though it's not hard to understand, it has a lot of wires to connect.
- To build a simpler system, you could either use a another ADC or an Arduino.
  - To get by with just one ADC chip, you could use MCP3008 ADC, which has eight inputs.
  - Pi + Arduino

Contents

Test Project: Posture Alarm (Arduino)

- Combining Piezo and IR Sensor

- **WHAT YOU'LL LEARN** in the *Posture Alarm* project
- Combine input, processing, and output.
  - Play tones with a piezo beeper.
  - Enclose your project.

Figure 3-18. Ready posture alarm

Test Project: Posture Alarm (Arduino)

- Piezo Beeper
  - A piezoelectric crystal changes shape when you apply voltage to it.
  - By using alternating current (AC) or a simple on-off square wave, you can make the piezo crystal vibrate.
  - This makes the air vibrate, and air vibration is sound.

Figure 3-21. Posture alarm build

Test Project: Posture Alarm (Arduino)

- You can easily create a square wave by repeatedly turning a data pin on and off with digitalWrite.
- Alternatively, you could use the built-in tone() function that uses a more advanced and complicated implementation to produce the same wave.

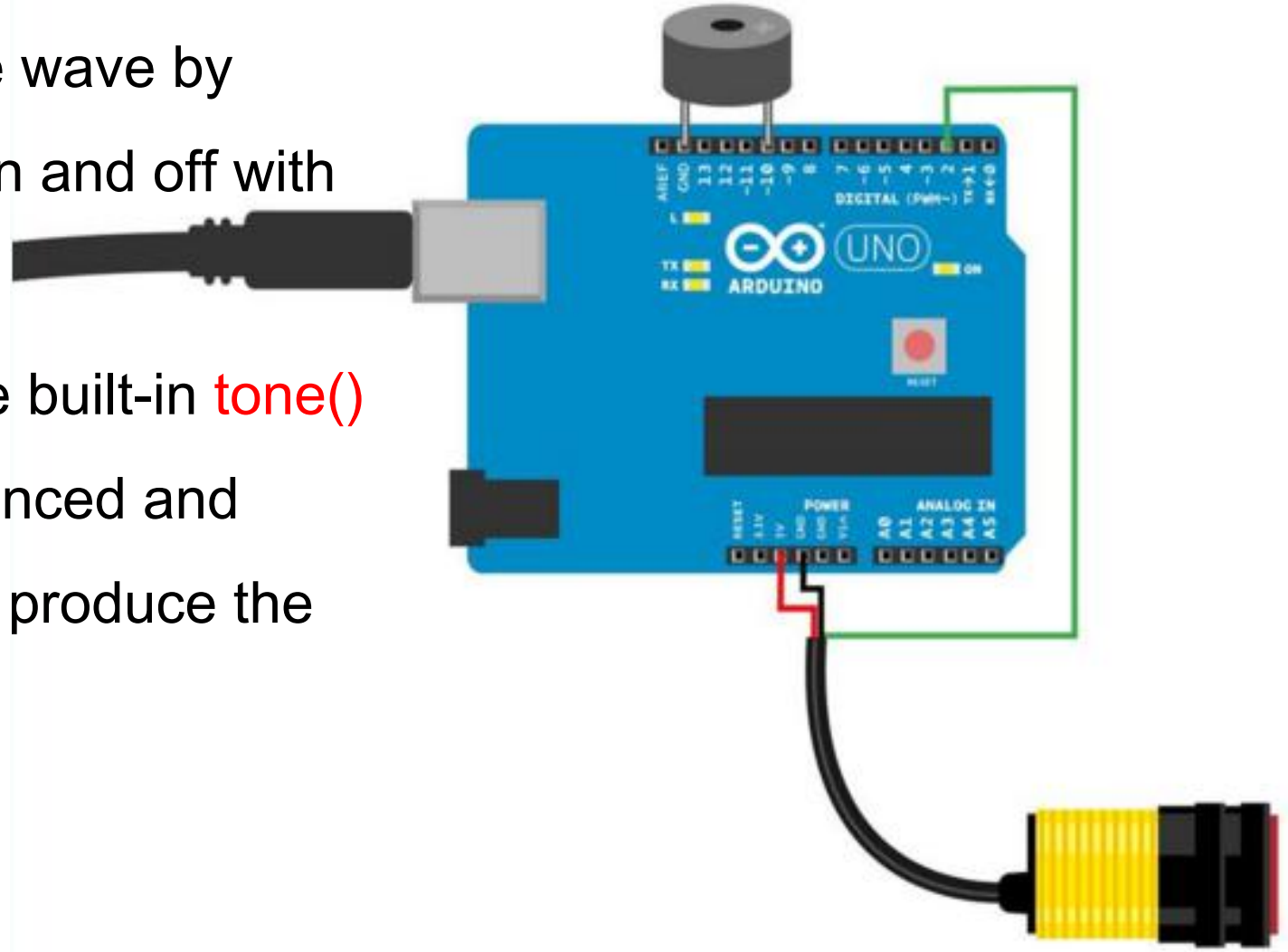


Figure 3-21. Posture alarm build

Test Project: Posture Alarm (Arduino)

Example 3-12. posture_alarm.ino

```
// posture_alarm.ino - sound an alarm when IR switch detects bad posture
// (c) BotBook.com - Karvinen, Karvinen, Valtokari

int speakerPin = 10;
const int sensorPin = 2;
int switchState = 0;
void wave(int pin, float frequency, int duration)  {
    //建立函数，以一定的频率、持续时间为参数，生成方波，触发压电式蜂鸣器发声
}
void alarm() // {
    //通过调用wave函数，使压电式蜂鸣器发声，并奏出音乐
}
void setup() {
    pinMode(speakerPin, OUTPUT);
    Serial.begin(115200);
    pinMode(sensorPin, INPUT);
}
```

```
void loop(){
   switchState = digitalRead(sensorPin);
   Serial.println(switchState,BIN);
   if (switchState==0) {       //
            alarm();           //
   }
   delay(10);
}
```

Test Project: Posture Alarm (Arduino)

```
void wave(int pin, float frequency, int duration)  {
    float period=1/frequency*1000*1000;                  // (us)  计算方波的周期

    //使用设定好的时间执行任务的常用模式:
    long int startTime=millis();        //首先将起始运行时间保存到变量中，millis()返回Arduino上电或复位后的运行时间
    while( (millis() - startTime) < duration) {   //然后，反复判断当前运行时间与起始时间的差，
                                                  //只要没有超过持续时间，就一直循环，产生方波
        digitalWrite(pin, HIGH);
        delayMicroseconds(period/2);
        digitalWrite(pin, LOW);
        delayMicroseconds(period/2);
    }
}
```

Test Project: Posture Alarm (Arduino)

```
void alarm() {    //通过调用wave函数，使压电式蜂鸣器发声，并奏出音乐
    wave(speakerPin, 440, 40);
    delay(25);
    wave(speakerPin, 300, 20);
    wave(speakerPin, 540, 40);
    delay(25);
    wave(speakerPin, 440, 20);
    wave(speakerPin, 640, 40);
    delay(25);
    wave(speakerPin, 540, 20);
}
```

Putting Everything in a Neat Package

Figure 3-22. Hole for the infrared sensor

Figure 3-23. From the back of the chassis, you can adjust the distance screw

Figure 3-24. Insides of posture alarm

How will you use distance sensors in your projects?

- You have now learned to measure distance using multiple methods.
- Your projects can know if something is near or how far it is to objects nearby. With more than one sensor, you can create more sophisticated behaviors.
- For example, combine two IR sensors with a servo motor and make it turn toward the direction of the nearest detected object.
- This way you would have a simple hand follower. Two IR receivers in a rover robot would enable it to follow flame.