

## Getting Started

As some functions including SPI are not supported with Pi4j yet, some projects covered in the C tutorial are not included in this tutorial. We will update once they are supported.

## Get Support and Offer Input

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- Product quality issues
- Product use and build issues
- Questions regarding the technology employed in our products for learning and education
- Your input and opinions are always welcome
- We also encourage your ideas and suggestions for new products and product improvements

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- Keep this product out of the reach of children under 6 years old.
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- This product contains small parts and parts, which are sharp. This product contains electrically conductive parts. **Use caution with electrically conductive parts near or around power supplies, batteries and powered (live) circuits.**
- When the product is turned ON, activated or tested, some parts will move or rotate. **To avoid injuries to hands and fingers keep them away from any moving parts!**
- It is possible that an improperly connected or shorted circuit may cause overheating. **Should this happen, immediately disconnect the power supply or remove the batteries and do not touch anything until it cools down!** When everything is safe and cool, review the product tutorial to identify the cause.
- Only operate the product in accordance with the instructions and guidelines of this tutorial, otherwise parts may be damaged or you could be injured.
- Store the product in a cool dry place and avoid exposing the product to direct sunlight.
- After use, always turn the power OFF and remove or unplug the batteries before storing.

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Freenove is committed to assist customers in their education of robotics, programming and electronic circuits so that they may transform their creative ideas into prototypes and new and innovative products. To this end, our services include but are not limited to:

- Educational and Entertaining Project Kits for Robots, Smart Cars and Drones
- Educational Kits to Learn Robotic Software Systems for Arduino, Raspberry Pi and micro:bit
- Electronic Component Assortments, Electronic Modules and Specialized Tools
- Product Development and Customization Services

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<http://www.freenove.com>

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# Raspberry Pi

So far, at this writing, Raspberry Pi has advanced to its fifth generation product offering. Version changes are accompanied by increases in upgrades in hardware and capabilities.

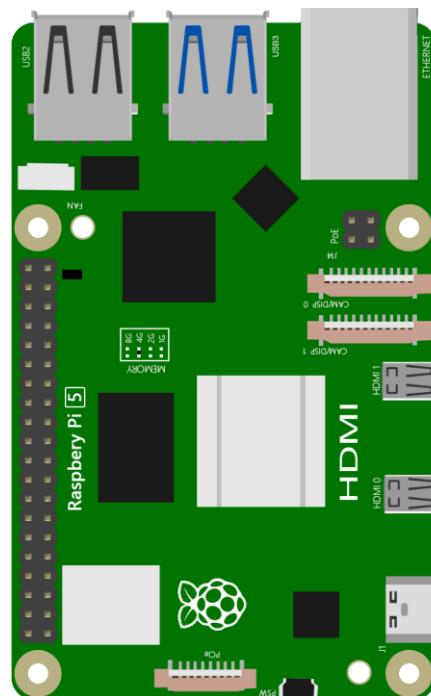
The A type and B type versions of the first generation products have been discontinued due to various reasons. What is most important is that other popular and currently available versions are consistent in the order and number of pins and their assigned designation of function, making compatibility of peripheral devices greatly enhanced between versions.

Below are the raspberry pi pictures and model pictures supported by this product. They have 40 pins.

Practicality picture of Raspberry Pi 5:



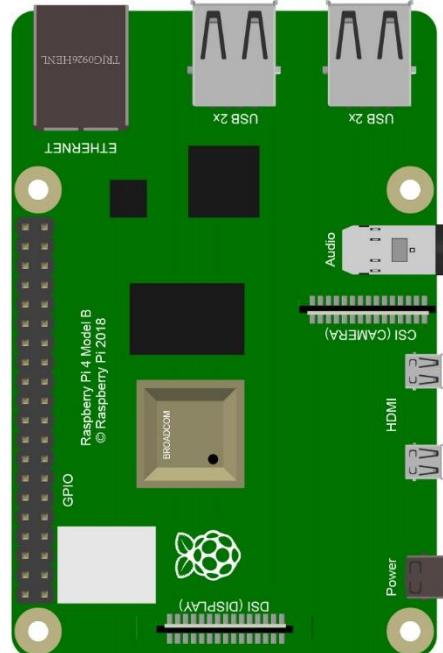
Model diagram of Raspberry Pi 5:



Actual image of Raspberry Pi 4 Model B:



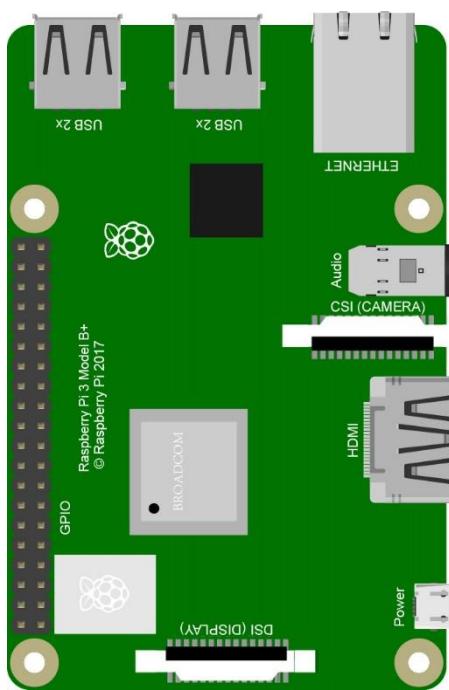
CAD image of Raspberry Pi 4 Model B:



Actual image of Raspberry Pi 3 Model B+:



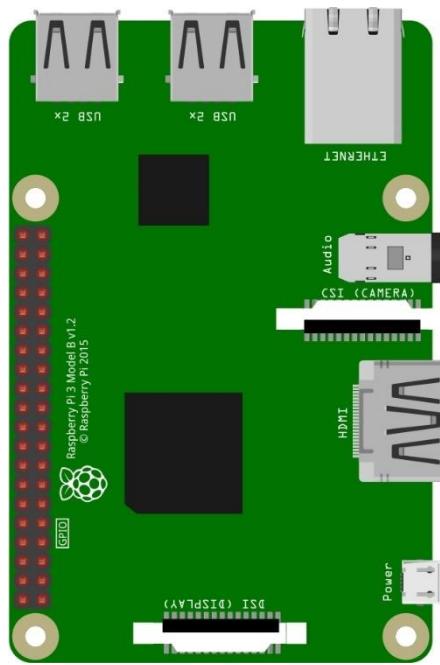
CAD image of Raspberry Pi 3 Model B+:



Actual image of Raspberry Pi 3 Model B:



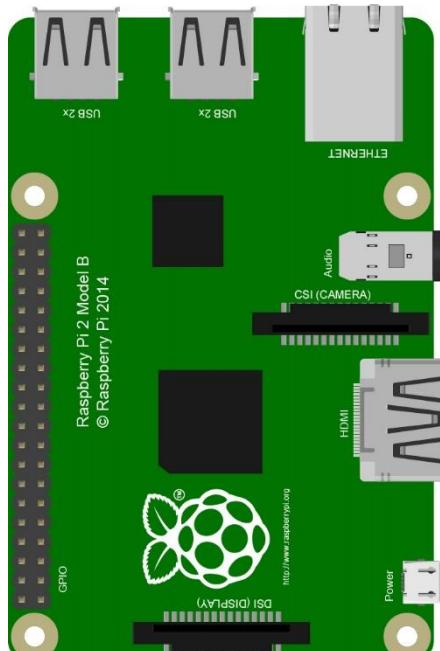
CAD image of Raspberry Pi 3 Model B:



Actual image of Raspberry Pi 2 Model B:



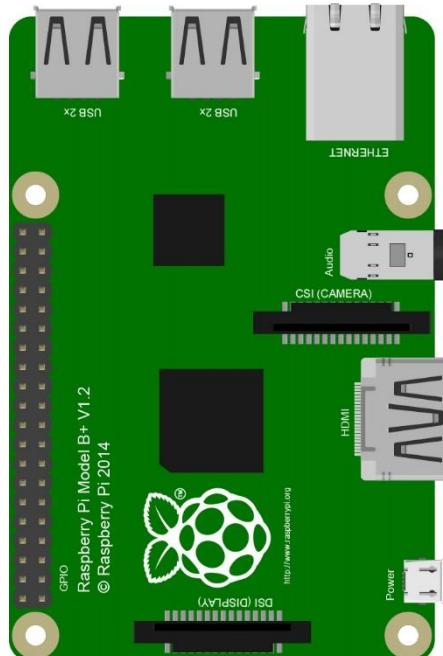
CAD image of Raspberry Pi 2 Model B:



Actual image of Raspberry Pi 1 Model B+:



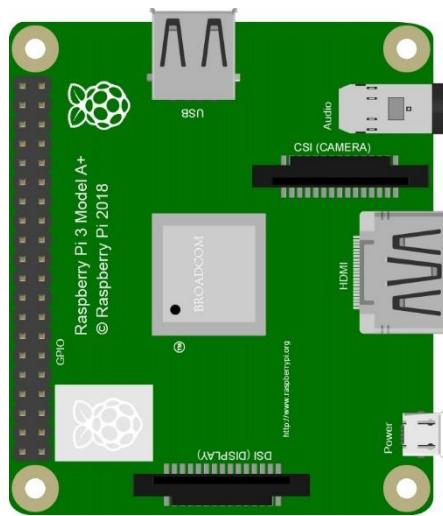
CAD image of Raspberry Pi 1 Model B+:



Actual image of Raspberry Pi 3 Model A+:



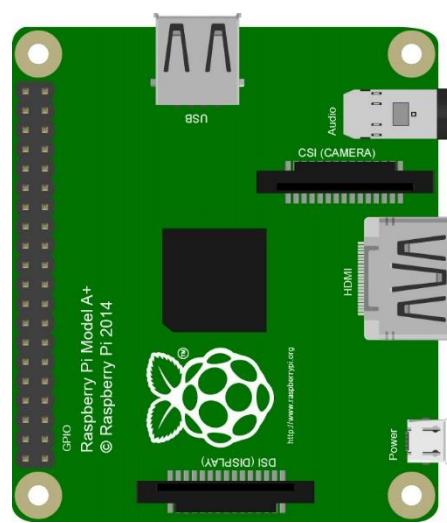
CAD image of Raspberry Pi 3 Model A+:



Actual image of Raspberry Pi 1 Model A+:



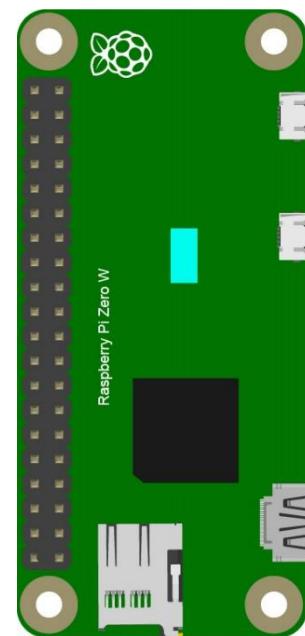
CAD image of Raspberry Pi 1 Model A+:



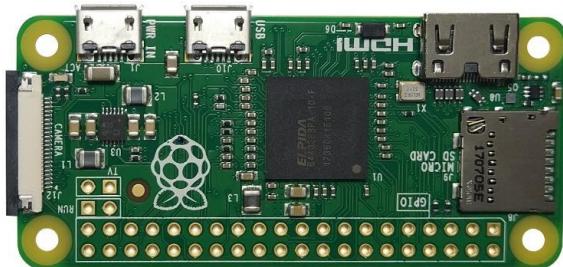
Actual image of Raspberry Pi Zero W:



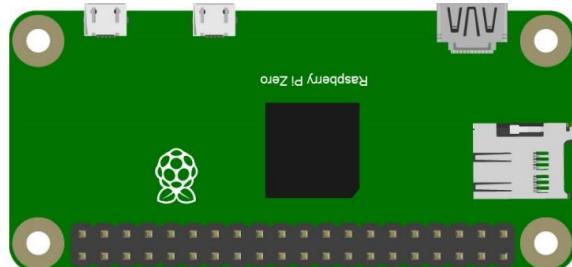
CAD image of Raspberry Pi Zero W:



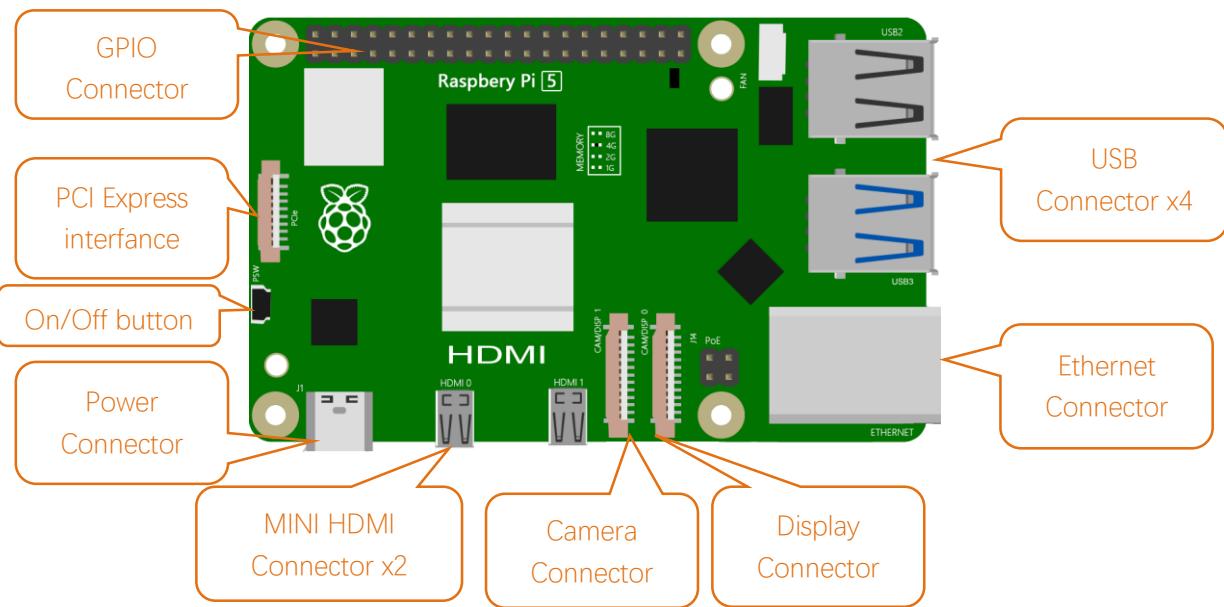
Actual image of Raspberry Pi Zero:



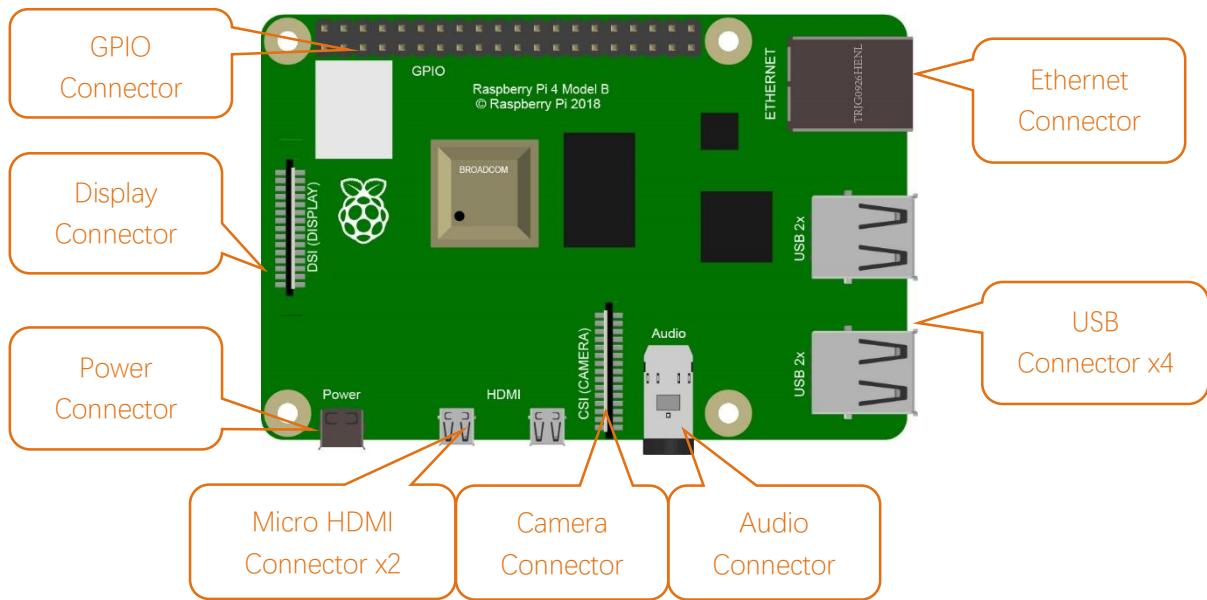
CAD image of Raspberry Pi Zero:



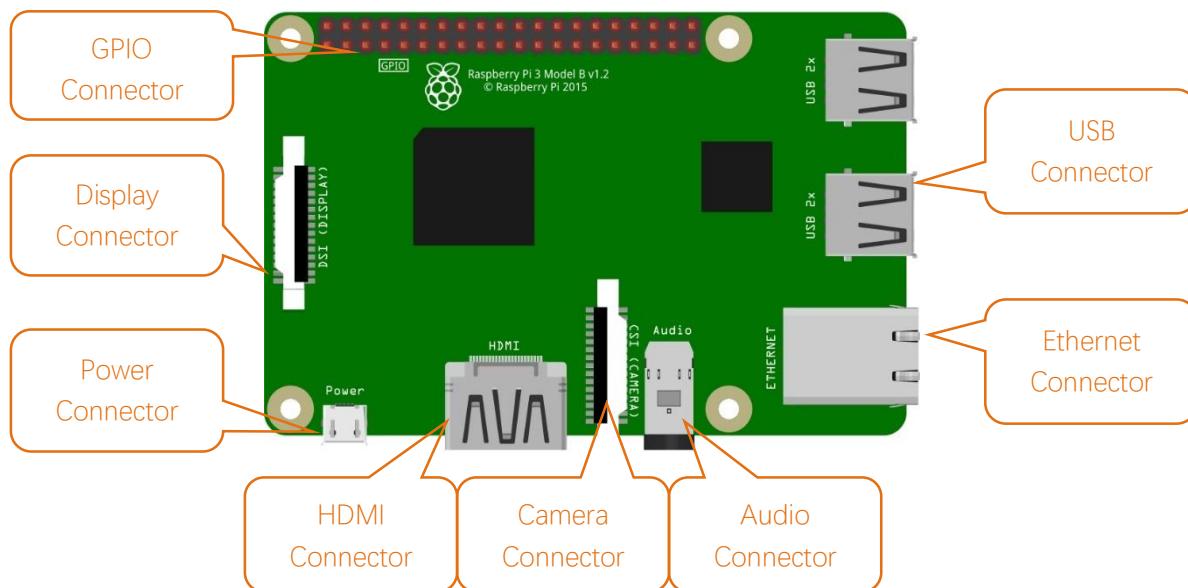
Below are the raspberry pi pictures and model pictures supported by this product. They have 40 pins. Hardware interface diagram of RPi 5 is shown below:



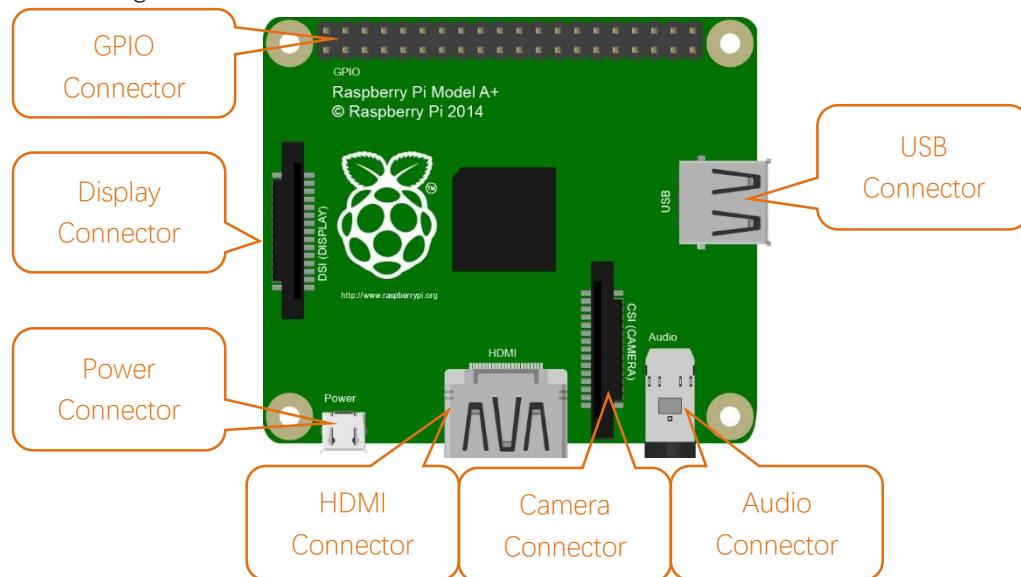
Hardware interface diagram of RPi 4B is shown below:



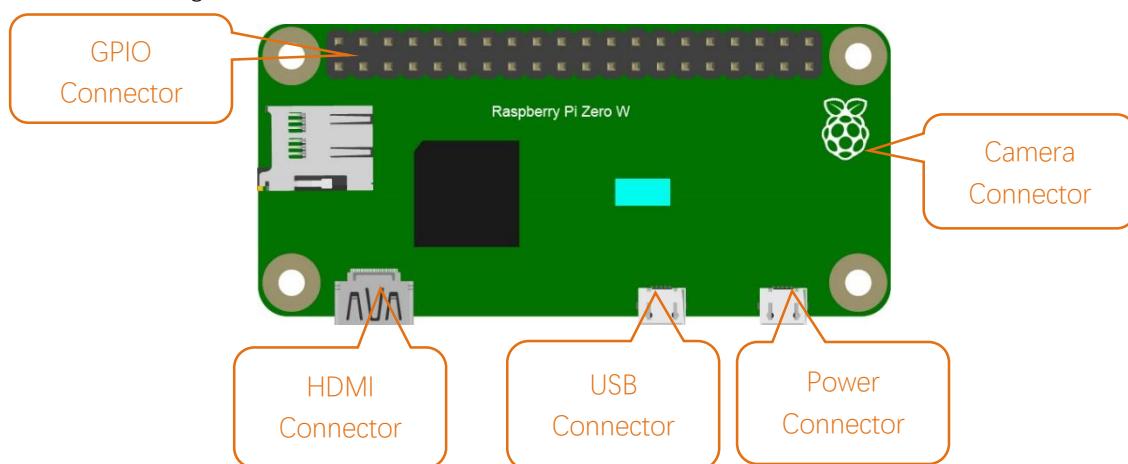
Hardware interface diagram of RPi 3B+/3B/2B/1B+:



Hardware interface diagram of RPi 3A+/A+:



Hardware interface diagram of RPi Zero/Zero W:

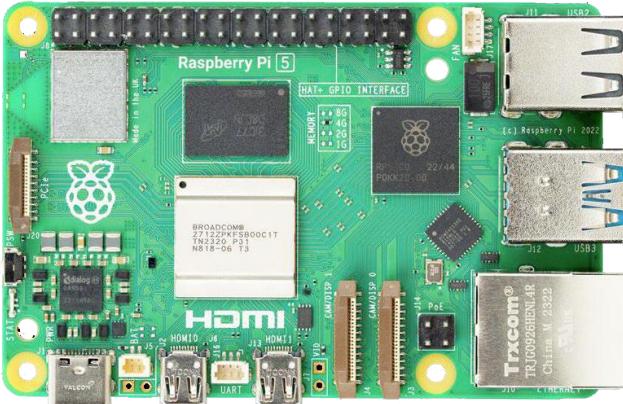
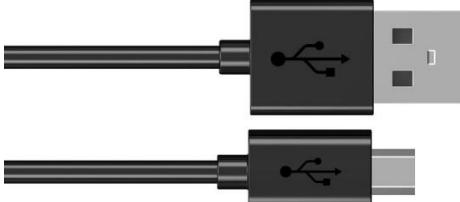


# Installing an Operating System

The first step is to install an operating system on your RPi so that it can be programmed and function. If you have installed a system in your RPi, you can start from Chapter 0 Preparation.

## Component List

### Required Components

Any Raspberry Pi with 40 GPIO	5V/3A Power Adapter. Note: Different versions of Raspberry Pi have different power requirements (please check the power requirements for yours on the chart in the following page.)
	
Micro or Type-C USB Cable x1	Micro SD Card (TF Card) x1, Card Reader x1
	

Power requirements of various versions of Raspberry Pi are shown in following table:

Product	Recommended PSU current capacity	Maximum total USB peripheral current draw	Typical bare-board active current consumption
Raspberry Pi 1 Model A	700mA	500mA	200mA
Raspberry Pi 1 Model B	1.2A	500mA	500mA
Raspberry Pi 1 Model A+	700mA	500mA	180mA
Raspberry Pi 1 Model B+	1.8A	1.2A	330mA
Raspberry Pi 2 Model B	1.8A	1.2A	350mA
Raspberry Pi 3 Model B	2.5A	1.2A	400mA
Raspberry Pi 3 Model A+	2.5A	Limited by PSU, board, and connector ratings only.	350mA
Raspberry Pi 3 Model B+	2.5A	1.2A	500mA
Raspberry Pi 4 Model B	3.0A	1.2A	600mA
Raspberry Pi 5	5.0A	1.6A (600mA if using a 3A power supply)	800mA
Raspberry Pi 400	3.0A	1.2A	800mA
Raspberry Pi Zero	1.2A	Limited by PSU, board, and connector ratings only	100mA
Raspberry Pi Zero W	1.2A	Limited by PSU, board, and connector ratings only.	150mA
Raspberry Pi Zero 2 W	2A	Limited by PSU, board, and connector ratings only.	350mA

For more details, please refer to <https://www.raspberrypi.org/help/faqs/#powerReqs>

In addition, RPi also needs an Ethernet network cable used to connect it to a WAN (Wide Area Network).

The Raspberry Pi 5 provides 1.6A of power to downstream USB peripherals when connected to a power supply capable of 5A at +5V (25W). When connected to any other compatible power supply, the Raspberry Pi 5 restricts downstream USB devices to 600mA of power.





## Optional Components

Under normal circumstances, there are two ways to login to Raspberry Pi: 1) Using a stand-alone monitor. 2) Using a remote desktop or laptop computer monitor “sharing” the PC monitor with your RPi.

### Required Accessories for Monitor

If you choose to use an independent monitor, mouse and keyboard, you also need the following accessories:

1. A display with a HDMI interface
2. A Mouse and a Keyboard with an USB interface

As to Pi Zero and Pi Zero W, you also need the following accessories:

1. A Mini-HDMI to HDMI Adapter and Cable.
2. A Micro-USB to USB-A Adapter and Cable (Micro USB OTG Cable).
3. A USB HUB.
4. USB to Ethernet Interface or USB Wi-Fi receiver.

For different Raspberry Pi Modules, the optional items may vary slightly but they all aim to convert the interfaces to Raspberry Pi standards.

	Pi Zero	Pi A+	Pi Zero W	Pi 3A+	Pi B+/2B	Pi 3B/3B+	Pi 4B	Pi 5
Monitor				Yes (All)				
Mouse				Yes (All)				
Keyboard				Yes (All)				
Micro-HDMI to HDMI Adapter & Cable	Yes	No	Yes	No	No	No	No	No
Micro-HDMI to HDMI Adapter & Cable				No			Yes	
Micro-USB to USB-A Adapter & Cable (Micro USB OTG Cable)	Yes	No	Yes			No		
USB HUB	Yes	Yes	Yes	Yes	No	No	No	No
USB to Ethernet Interface	select one from two or select two from two		optional		Internal Integration	Internal Integration		
USB Wi-Fi Receiver			Internal Integration		optional			

## Required Accessories for Remote Desktop

If you do not have an independent monitor, or if you want to use a remote desktop, you first need to login to Raspberry Pi through SSH, and then open the VNC or RDP service. This requires the following accessories.

	Pi Zero	Pi Zero W	Pi A+	Pi 3A+	Pi B+/2B	Pi 3B/3B+/4B/5
Micro-USB to USB-A Adapter & Cable (Micro USB OTG Cable)	Yes	Yes	No			NO
USB to Ethernet interface	Yes	Yes	Yes			



## Raspberry Pi OS

Without Screen - Use Raspberry Pi - under Windows PC: <https://youtu.be/YND0RUuP-to>

With Screen - Use Raspberry Pi - under Windows PC: <https://youtu.be/HEywFsFrj3I>

### Automatically Method

You can follow the official method to install the system for raspberry pi via visiting link below:

<https://projects.raspberrypi.org/en/projects/raspberry-pi-setting-up/2>

In this way, the system will be downloaded **automatically** via the application.

### Manually Method

After installing the Imager Tool in the [link above](#). You can **also** download the system **manually** first.

Visit <https://www.raspberrypi.org/downloads/>

**Manually install an operating system image**

Browse a range of operating systems provided by Raspberry Pi and by other organisations, and download them to install manually.

[See all download options](#)



The image is for reference only, please select the latest version.

**Raspberry Pi OS (64-bit)**

<p>Compatible with:</p> <p><a href="#">3B</a> <a href="#">3B+</a> <a href="#">3A+</a> <a href="#">4B</a> <a href="#">400</a>  <a href="#">5</a> <a href="#">CM3</a> <a href="#">CM3+</a> <a href="#">CM4</a>  <a href="#">CM4S</a> <a href="#">Zero 2 W</a></p>	<p><b>Raspberry Pi OS with desktop</b></p> <p>Release date: July 4th 2024  System: 64-bit  Kernel version: 6.6  Debian version: 12 (bookworm)  Size: 1,142MB  <a href="#">Show SHA256 file integrity hash</a>  <a href="#">Release notes</a></p> <p style="text-align: right;"><a href="#" style="background-color: #0056b3; color: white; padding: 5px 15px; border-radius: 5px;">Download</a>  <a href="#">Download torrent</a> <a href="#">Archive</a></p> <hr/> <p><b>Raspberry Pi OS with desktop and recommended software</b></p> <p>Release date: July 4th 2024  System: 64-bit  Kernel version: 6.6  Debian version: 12 (bookworm)  Size: 2,890MB  <a href="#">Show SHA256 file integrity hash</a>  <a href="#">Release notes</a></p> <p style="text-align: right;"><a href="#" style="background-color: #0056b3; color: white; padding: 5px 15px; border-radius: 5px;">Download</a>  <a href="#">Download torrent</a> <a href="#">Archive</a></p>
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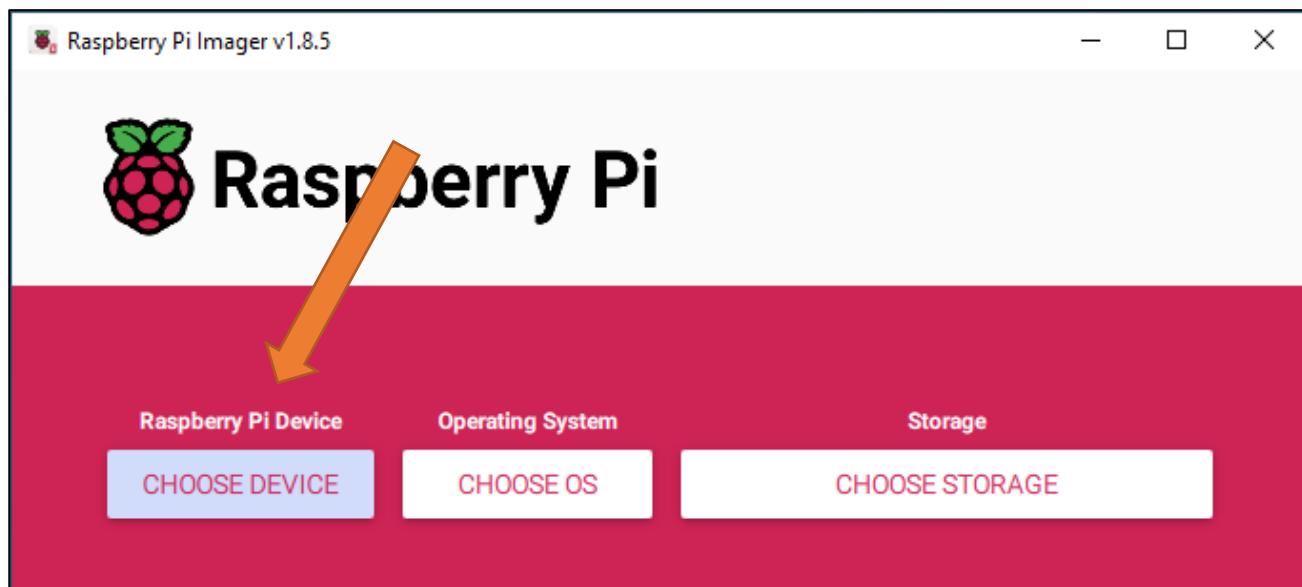
Then the zip file is downloaded.

### Write System to Micro SD Card

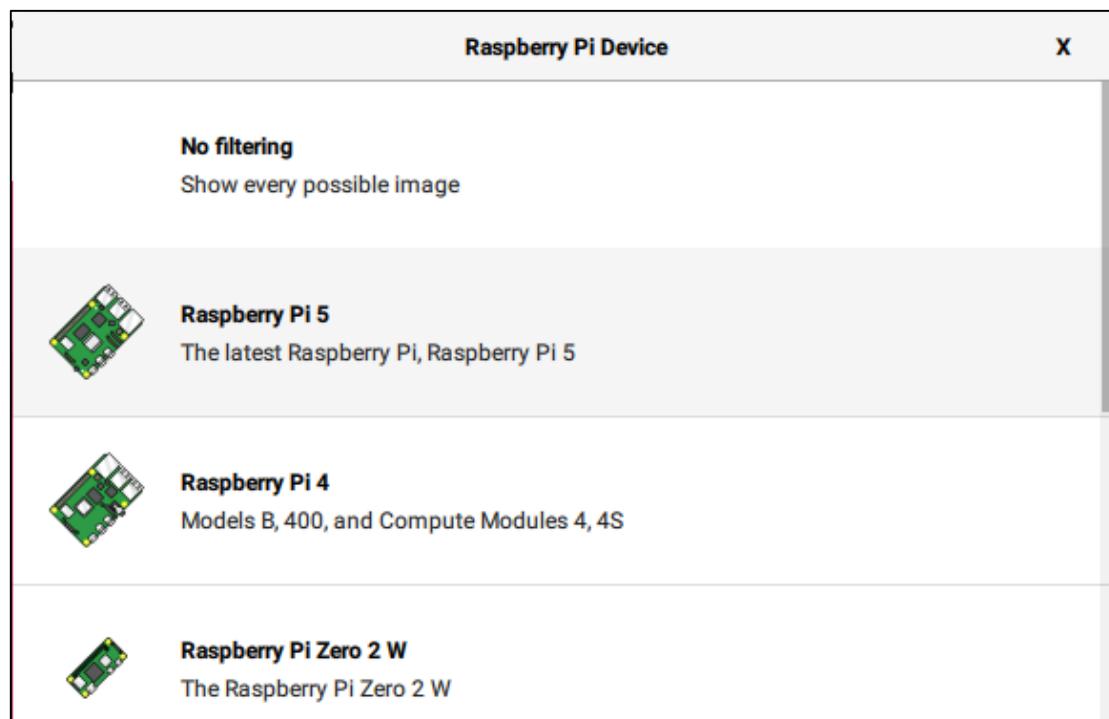
First, put your Micro SD card into card reader and connect it to USB port of PC.



Then open imager toll. Clicked Choose Device.

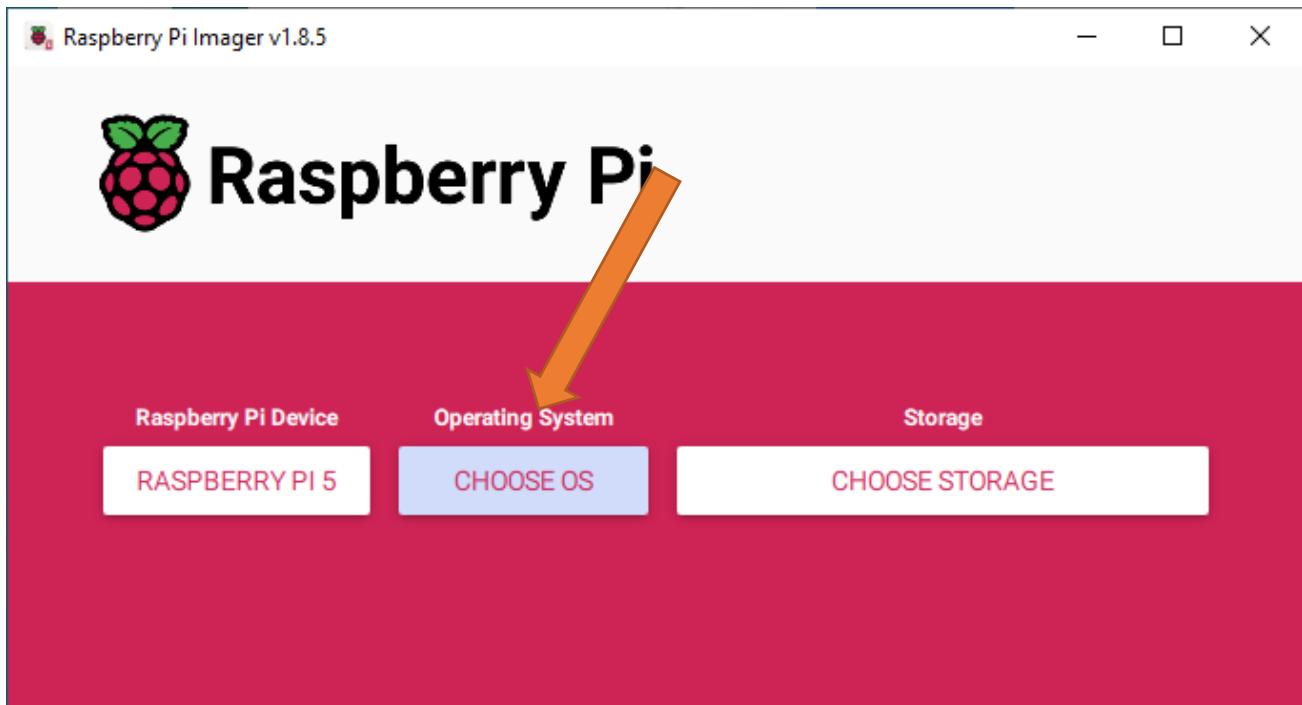


Select a Raspberry PI Device based on your Raspberry PI version. It will help us filter out the right version of the system for the Raspberry PI.

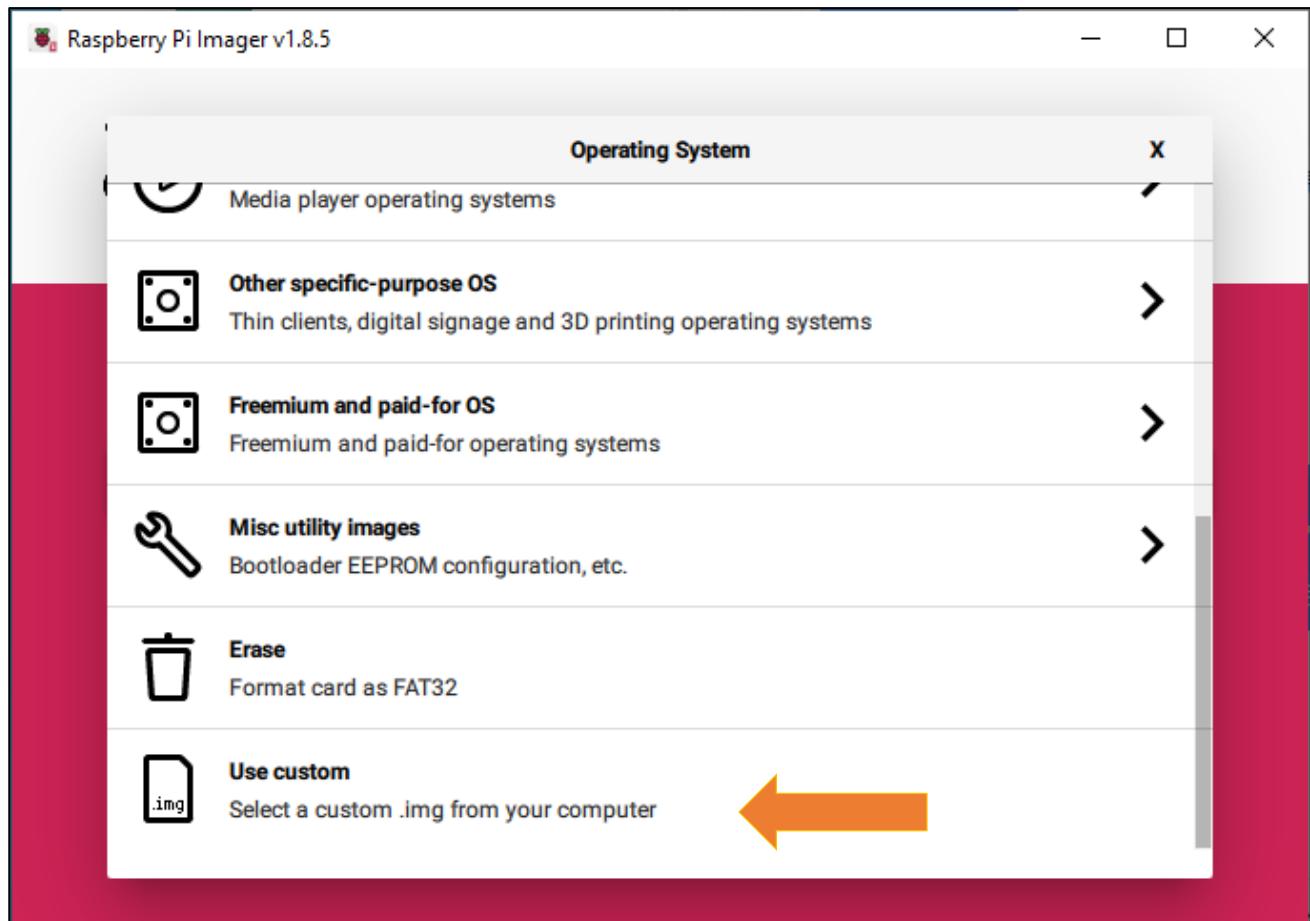




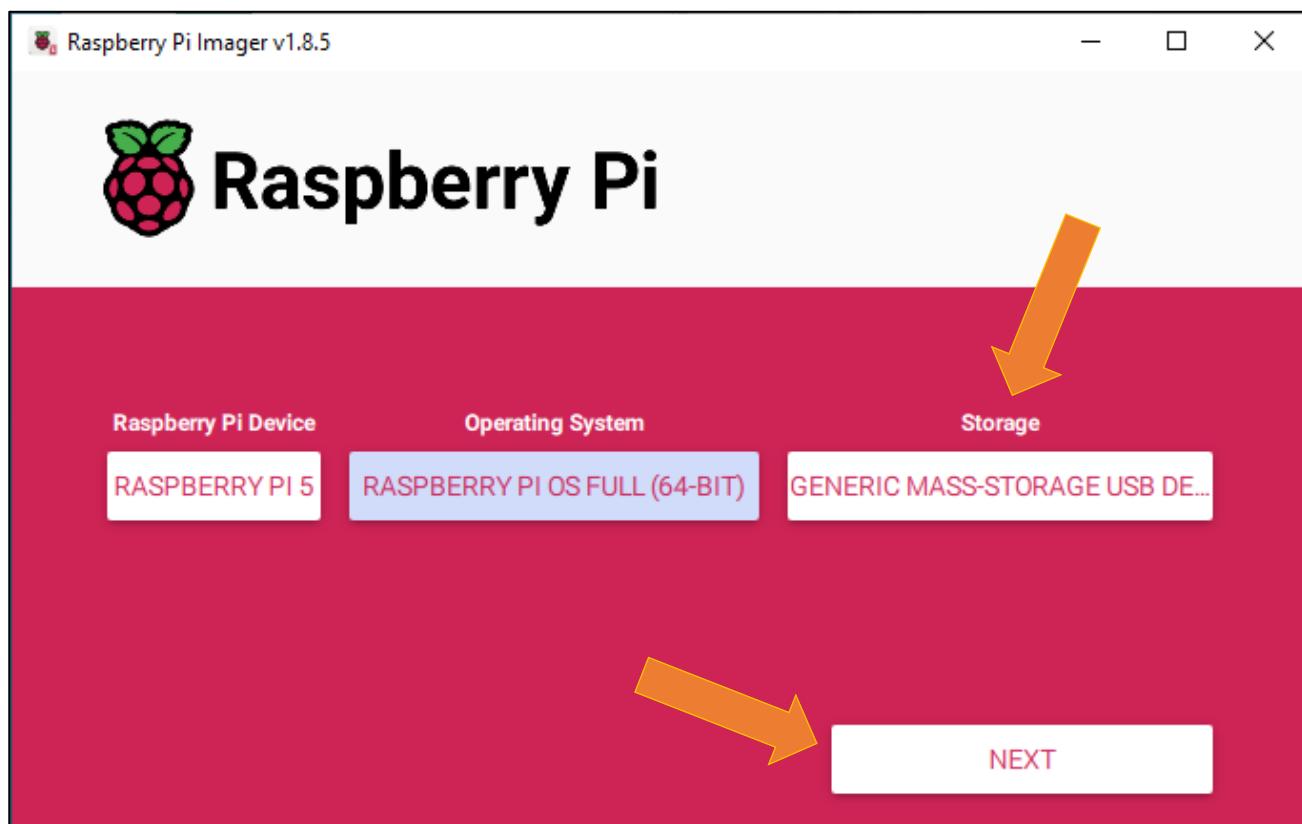
Clicked Operating System:



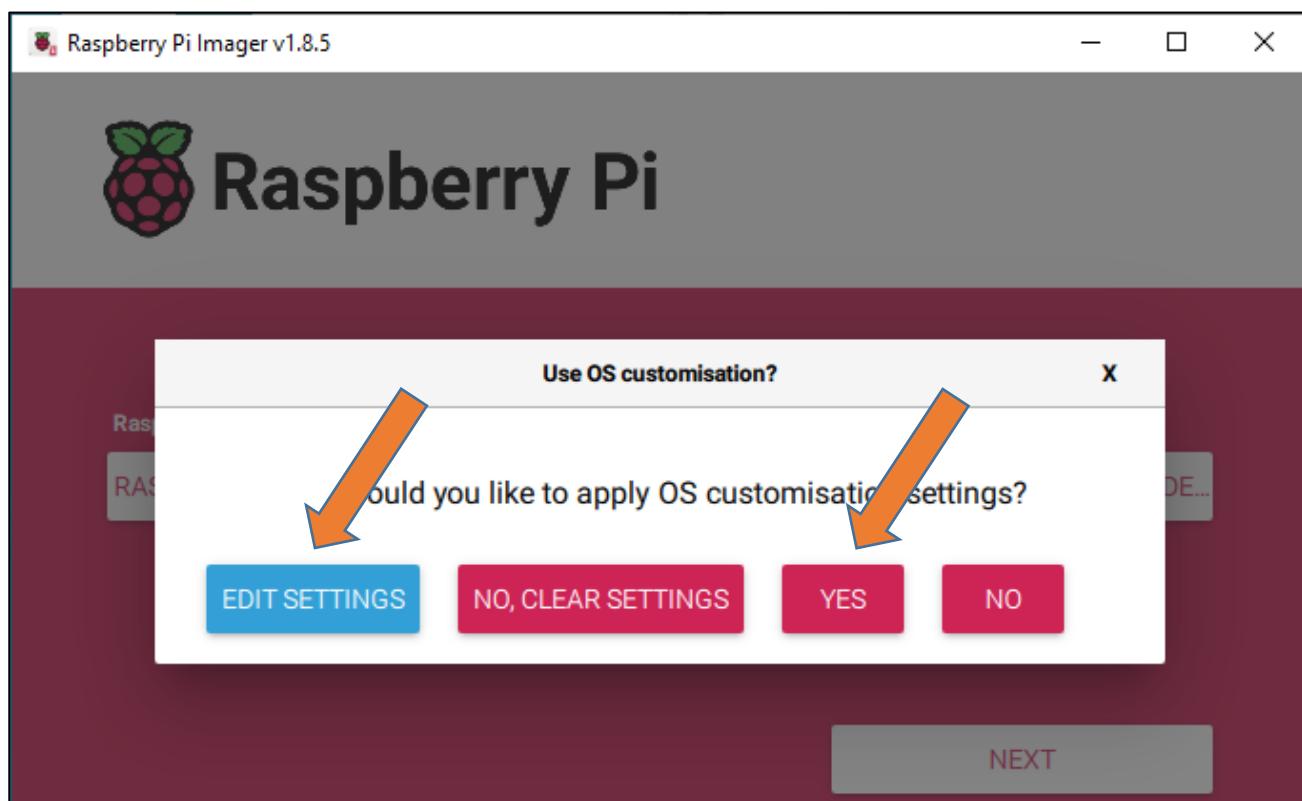
Choose system that you just downloaded in Use custom.



Choose the SD card. Then click "Next".

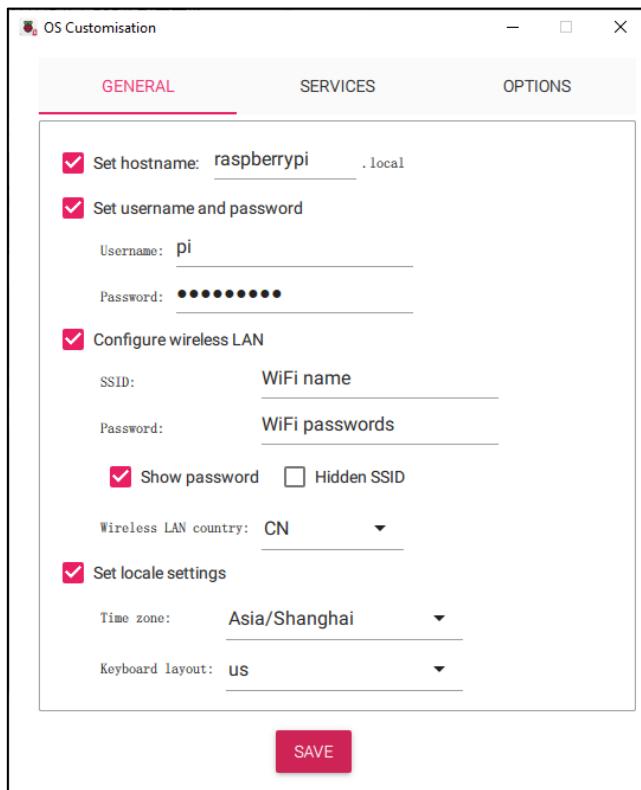


You can configure the Raspberry Pi according to your needs.

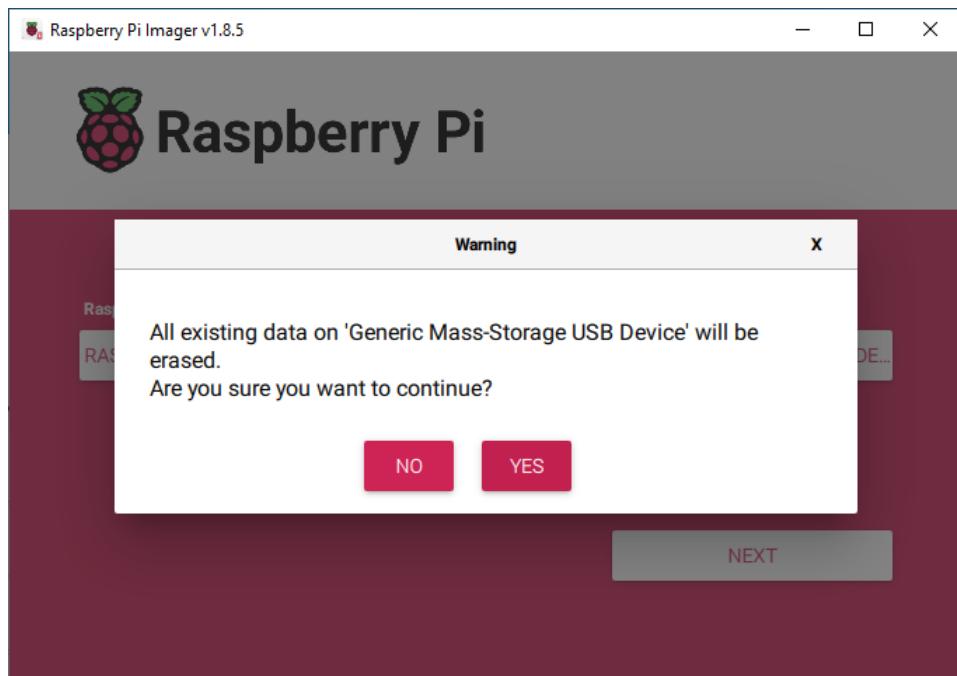


## Enable ssh and configure WiFi

On the GENERAL screen, configure your information based on your actual situation.

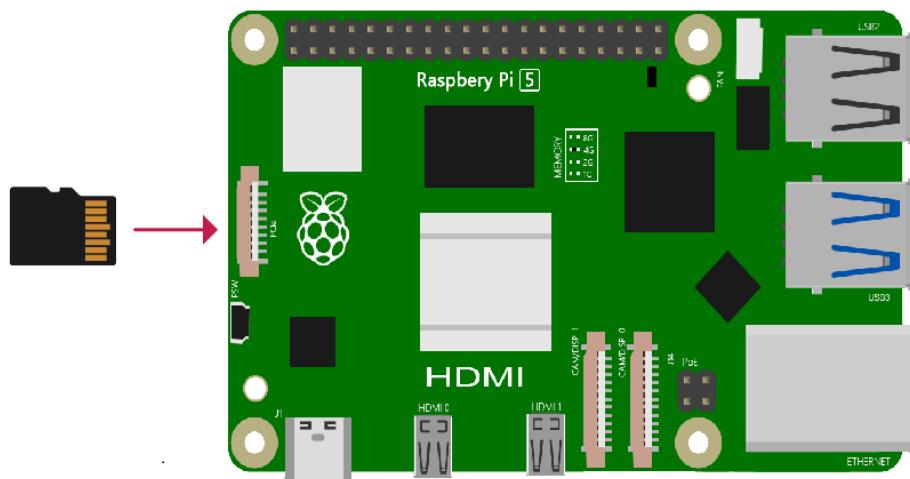


Click Save, in the new screen, click Yes, wait for SD to brush into the Raspberry system.



## Insert SD card

Then remove SD card from card reader and insert it into Raspberry Pi.



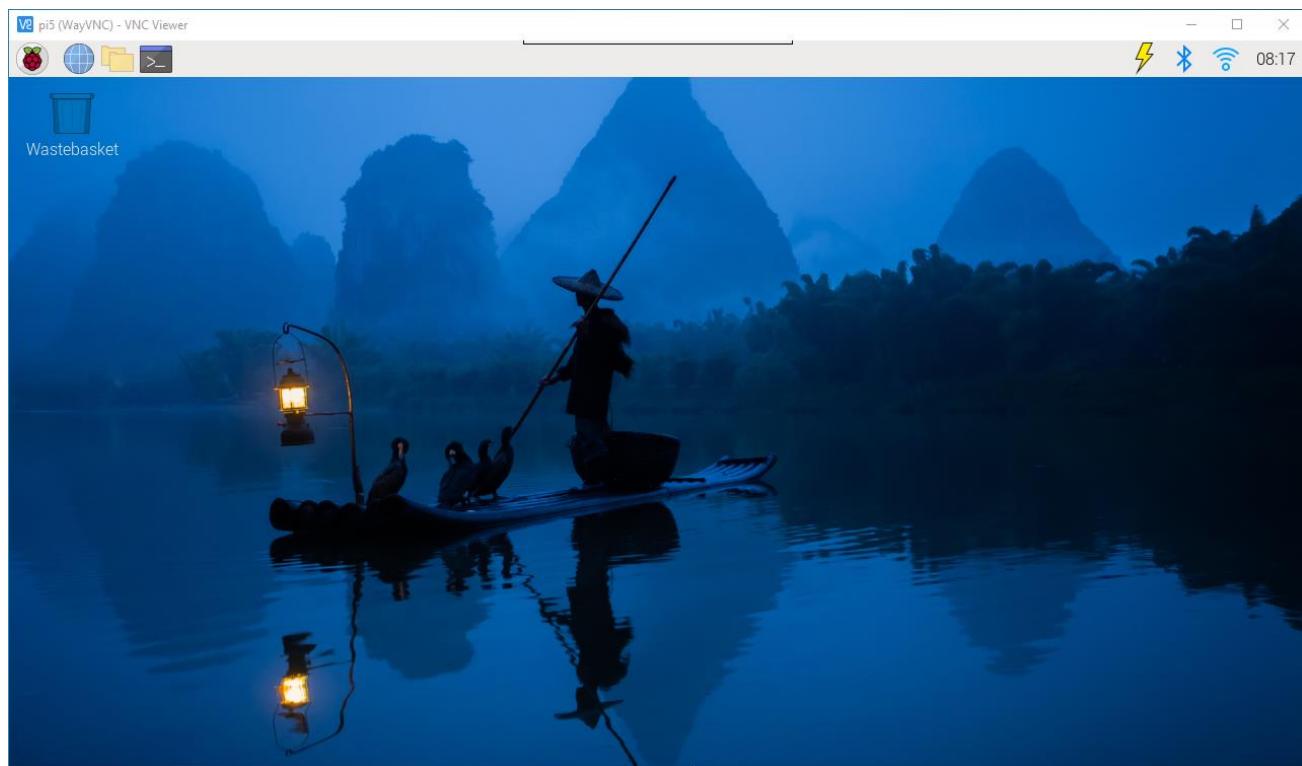
Connect to the power supply and wait for the Raspberry Pi to turn on.

## Getting Started with Raspberry Pi

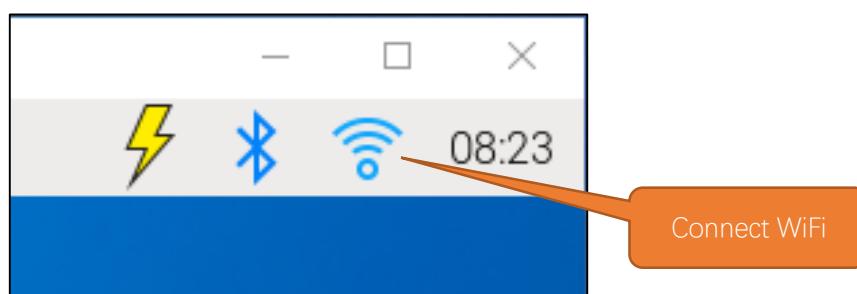
### Monitor desktop

If you do not have a spare monitor, please skip to next section [Remote desktop & VNC](#). If you have a spare monitor, please follow the steps in this section.

After the system is written successfully, take out Micro SD Card and put it into the SD card slot of RPi. Then connect your RPi to the monitor through the HDMI port, attach your mouse and keyboard through the USB ports, attach a network cable to the network port and finally, connect your power supply (making sure that it meets the specifications required by your RPi Module Version). Your RPi should start (power up). Later, after setup, you will need to enter your user name and password to login. The default user name: pi; password: raspberry. After login, you should see the following screen.



Congratulations! You have successfully installed the RASPBERRY PI OS operating system on your RPi. Raspberry Pi 5, 4B, 3B+/3B integrates a Wi-Fi adaptor. You can use it to connect to your Wi-Fi. Then you can use the wireless remote desktop to control your RPi. This will be helpful for the following work. Raspberry Pi of other models can use wireless remote desktop through accessing an external USB wireless card.



## Remote desktop & VNC

If you have logged in Raspberry Pi via display, you can skip to [VNC Viewer](#).

If you don't have a spare display, mouse and keyboard for your RPi, you can use a remote desktop to share a display, keyboard, and mouse with your PC. Below is how to use:

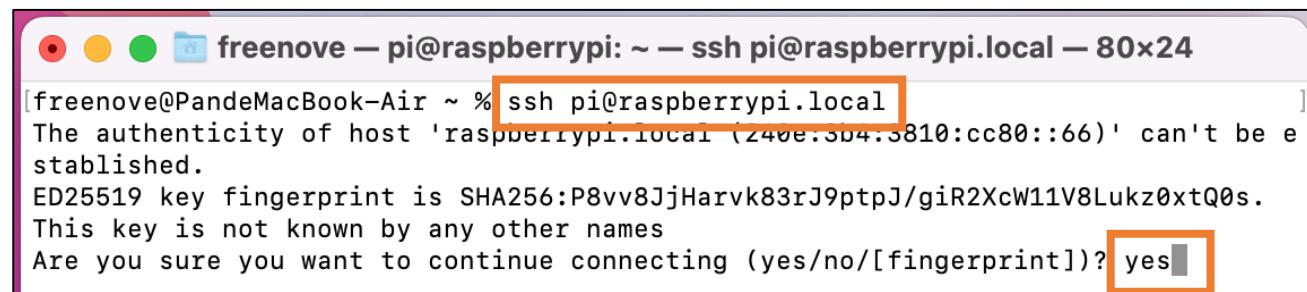
[MAC OS remote desktop](#) and [Windows OS remote desktop](#).

### MAC OS Remote Desktop

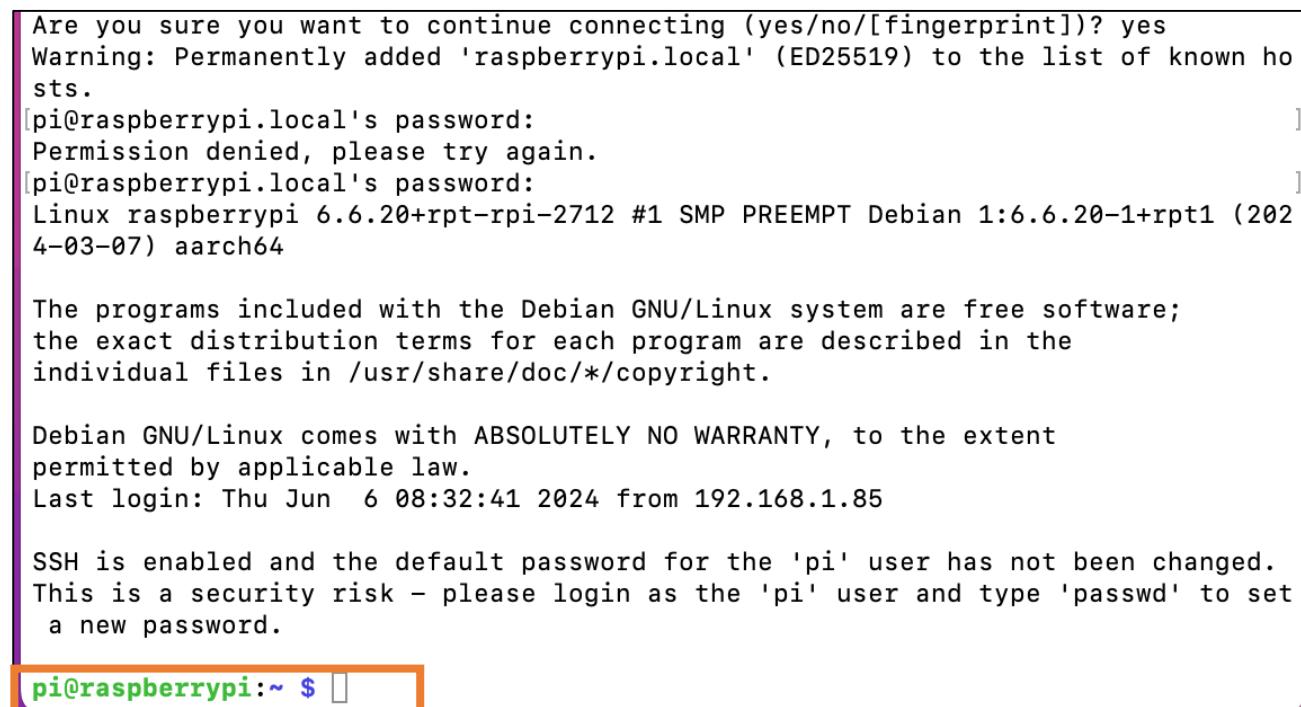
Open the terminal and type following command. **If this command doesn't work, please move to next page.**

```
ssh pi@raspberrypi.local
```

The password is **raspberry** by default, case sensitive. You may need to type **yes** during the process.



```
freenove — pi@raspberrypi: ~ — ssh pi@raspberrypi.local — 80x24
[freenove@PandeMacBook-Air ~ % ssh pi@raspberrypi.local
The authenticity of host 'raspberrypi.local (240e.3b4.3810:cc80::66)' can't be established.
ED25519 key fingerprint is SHA256:P8vv8JjHarvk83rJ9ptpJ/giR2XcW11V8Lukz0xtQ0s.
This key is not known by any other names
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes]
```



```
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added 'raspberrypi.local' (ED25519) to the list of known hosts.
[pi@raspberrypi.local's password:
Permission denied, please try again.
[pi@raspberrypi.local's password:
Linux raspberrypi 6.6.20+rpi-2712 #1 SMP PREEMPT Debian 1:6.6.20-1+rpi1 (202
4-03-07) aarch64

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Thu Jun  6 08:32:41 2024 from 192.168.1.85

SSH is enabled and the default password for the 'pi' user has not been changed.
This is a security risk - please login as the 'pi' user and type 'passwd' to set
a new password.

pi@raspberrypi:~ $ ]
```

You can also use the IP address to log in Pi.

Enter **router** client to **inquiry IP address** named "raspberry pi". For example, I have inquired to **my RPi IP address**, and it is "192.168.1.95".

Open the terminal and type following command.

```
ssh pi@192.168.1.95
```

When you see **pi@raspberrypi:~ \$**, you have logged in Pi successfully. Then you can skip to next section.

```
freenove — pi@raspberrypi: ~ — ssh pi@192.168.1.95 — 80x24
[freenove@PandeMacBook-Air ~ % ssh pi@192.168.1.95
The authenticity of host '192.168.1.95 (192.168.1.95)' can't be established.
ED25519 key fingerprint is SHA256:P8vv8JjHarvk83rJ9ptpJ/giR2XcW11V8Lukz0xtQ0s.
This host key is known by the following other names/addresses:
  ~/.ssh/known_hosts:1: raspberrypi.local
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added '192.168.1.95' (ED25519) to the list of known hosts.
[pi@192.168.1.95's password:
Linux raspberrypi 6.6.20+rpt-rpi-2712 #1 SMP PREEMPT Debian 1:6.6.20-1+rpt1 (202
4-03-07) aarch64

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Thu Jun  6 08:36:09 2024 from 240e:3b4:3810:cc80:bc5d:ebed:287f:f6ae

SSH is enabled and the default password for the 'pi' user has not been changed.
This is a security risk - please login as the 'pi' user and type 'passwd' to set
a new password.

pi@raspberrypi:~ $ ]
```

Then you can skip to [VNC Viewer](#).

## Windows OS Remote Desktop

If you are using win10, you can use follow way to login Raspberry Pi without desktop.

Press Win+R. Enter cmd. Then use this command to check IP:

```
ping -4 raspberrypi.local
```

```
C:\Windows\system32\cmd.exe
Microsoft Windows [Version 10.0.19045.4412]
(c) Microsoft Corporation. All rights reserved.

C:\Users\DESKTOP-LIN>ping -4 raspberrypi.local

Pinging raspberrypi.local [192.168.1.95] with 32 bytes of data:
Reply from 192.168.1.95: bytes=32 time=6ms TTL=64
Reply from 192.168.1.95: bytes=32 time=8ms TTL=64
Reply from 192.168.1.95: bytes=32 time=7ms TTL=64
Reply from 192.168.1.95: bytes=32 time=5ms TTL=64

Ping statistics for 192.168.1.95:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 5ms, Maximum = 8ms, Average = 6ms

C:\Users\DESKTOP-LIN>
```

Then 192.168.1.147 is my Raspberry Pi IP.

Or enter **router** client to **inquiry IP address** named "raspberrypi". For example, I have inquired to **my RPi IP address and it is "192.168.1.95"**.

```
ssh pi@xxxxxxxxxxxx(IP address)
```

Enter the following command:

```
ssh pi@192.168.1.95
```

```
pi@raspberrypi: ~
C:\Users\DESKTOP-LIN>ssh pi@192.168.1.95
The authenticity of host '192.168.1.95 (192.168.1.95)' can't be established.
ECDSA key fingerprint is SHA256:tHbTxASRQQ/zy4CT4vSJvzAYW9FdIUPVqq7/2Bf3cIM.
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added '192.168.1.95' (ECDSA) to the list of known hosts.
pi@192.168.1.95's password:
Linux raspberrypi 6.6.20+rpt-rpi-2712 #1 SMP PREEMPT Debian 1:6.6.20-1+rpt1 (2024-03-07) aarch64

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/*copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Thu Jun  6 08:39:59 2024 from 192.168.1.85

SSH is enabled and the default password for the 'pi' user has not been changed.
This is a security risk - please login as the 'pi' user and type 'passwd' to set a new password.

pi@raspberrypi: ~ $
```



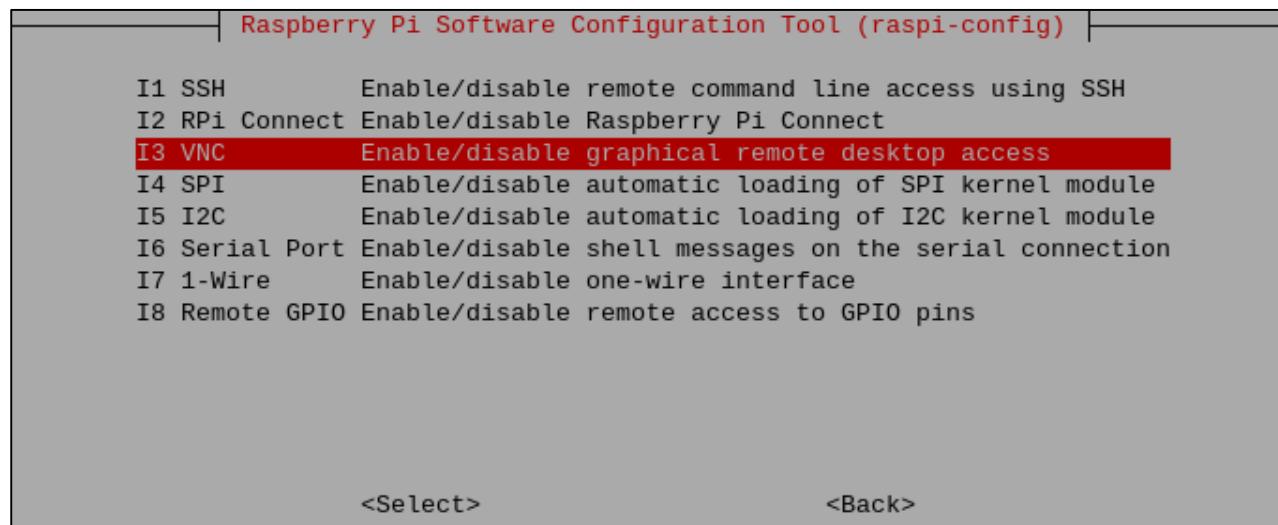
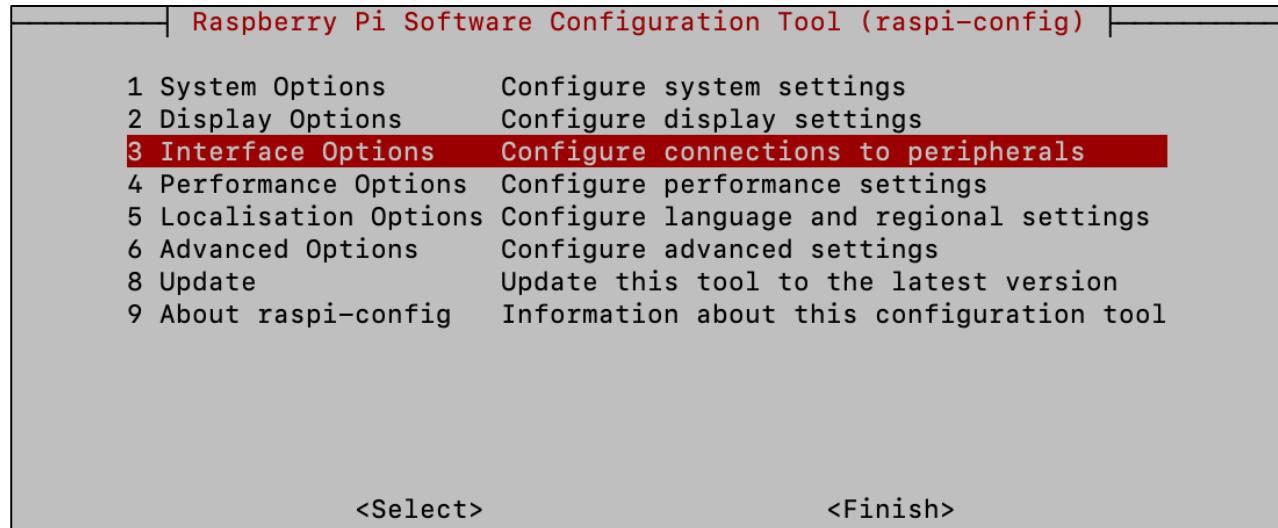
### Enable VNC

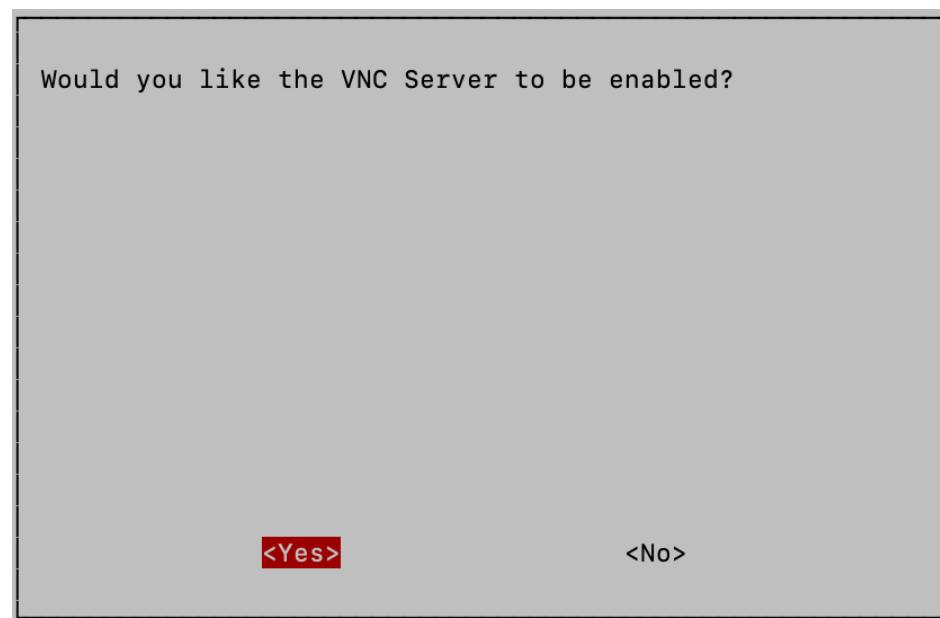
Type the following command. Select Interface Options → P5 VNC → Enter → Yes → OK. Here Raspberry Pi may need be restarted, and choose ok. Then open VNC interface.

```
sudo raspi-config
```

```
SSH is enabled and the default password for the 'pi' user has not been changed.  
This is a security risk - please login as the 'pi' user and type 'passwd' to set  
a new password.
```

```
pi@raspberrypi:~ $ sudo raspi-config
```

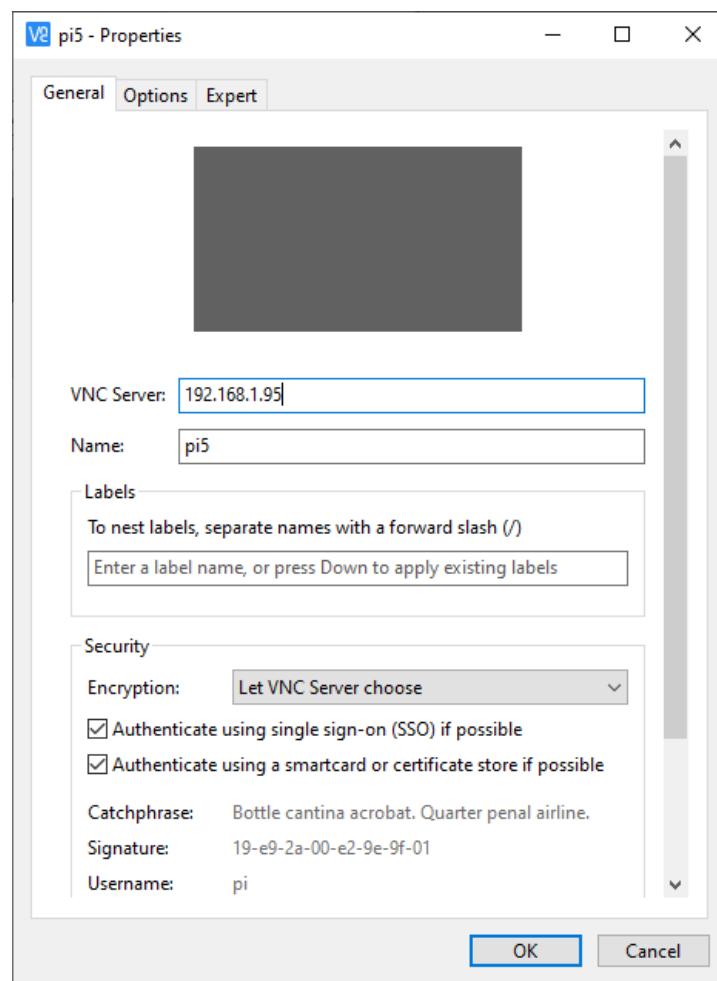




Then download and install VNC Viewer according to your computer system by click following link:

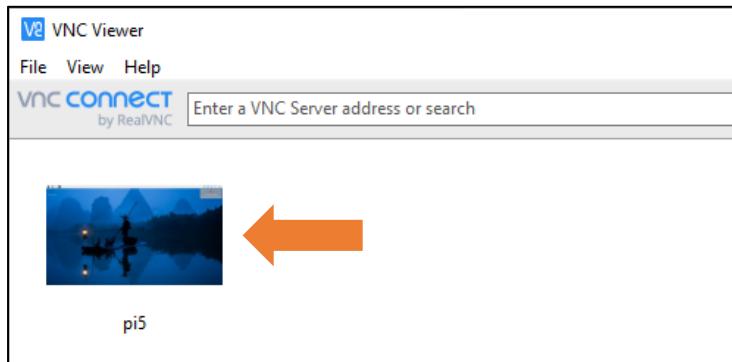
<https://www.realvnc.com/en/connect/download/viewer/>

After installation is completed, open VNC Viewer. Click File → New Connection. The interface is shown below.

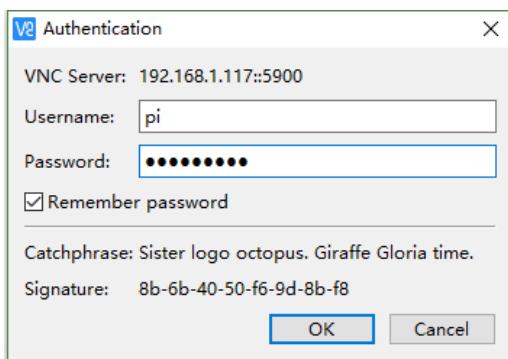


Enter ip address of your Raspberry Pi and fill in a name. Then click OK.

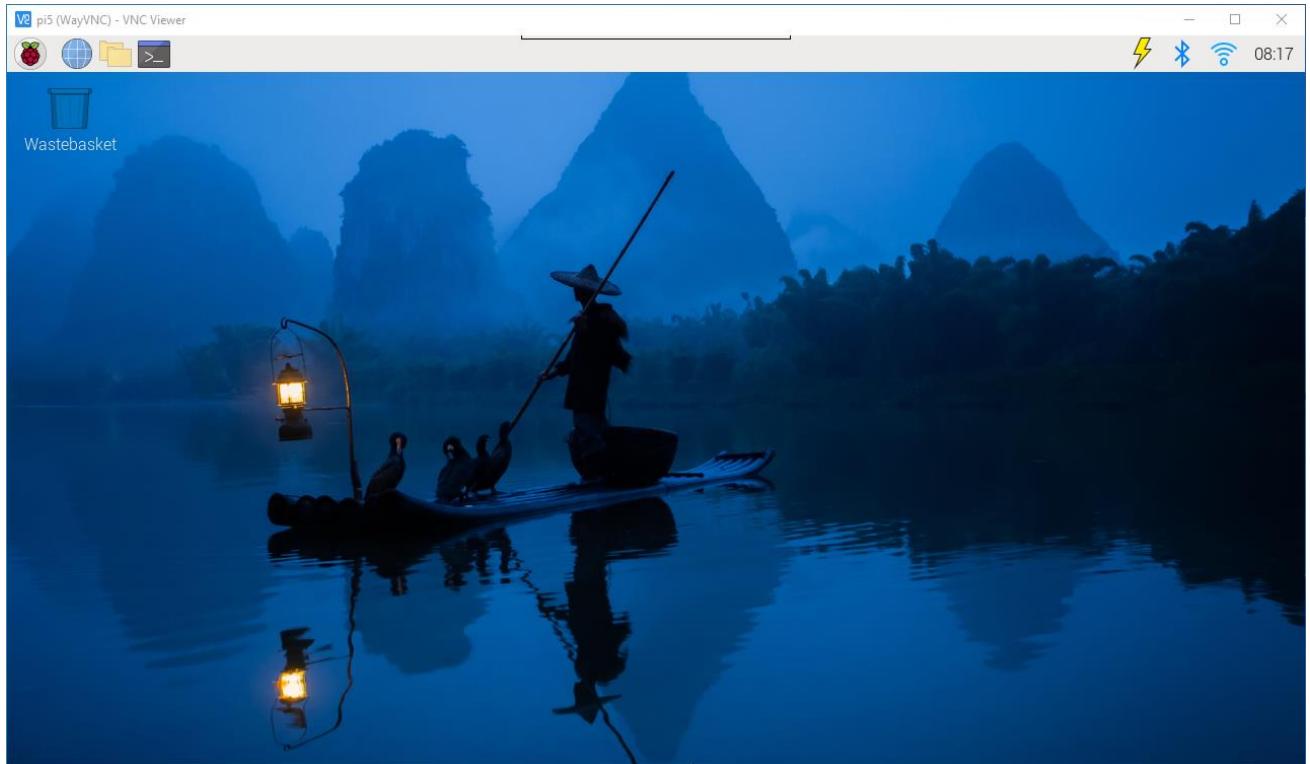
Then on the VNC Viewer panel, double-click new connection you just created,



and the following dialog box pops up.



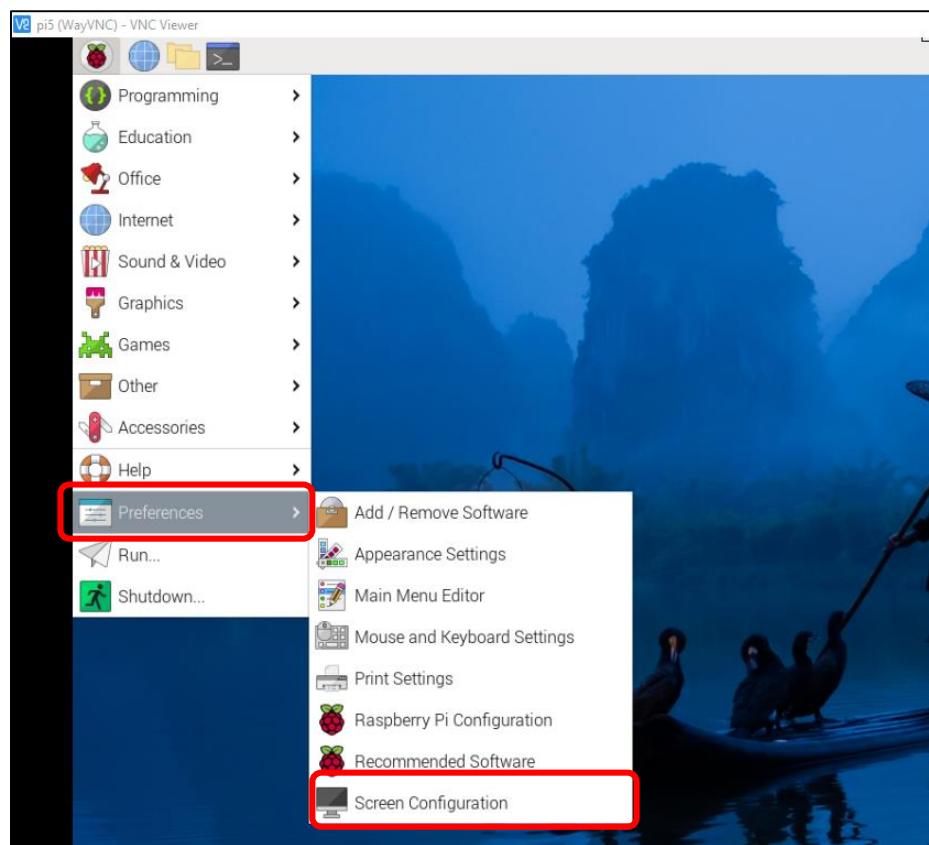
Enter username: **pi** and Password: **raspberry**. And click OK.



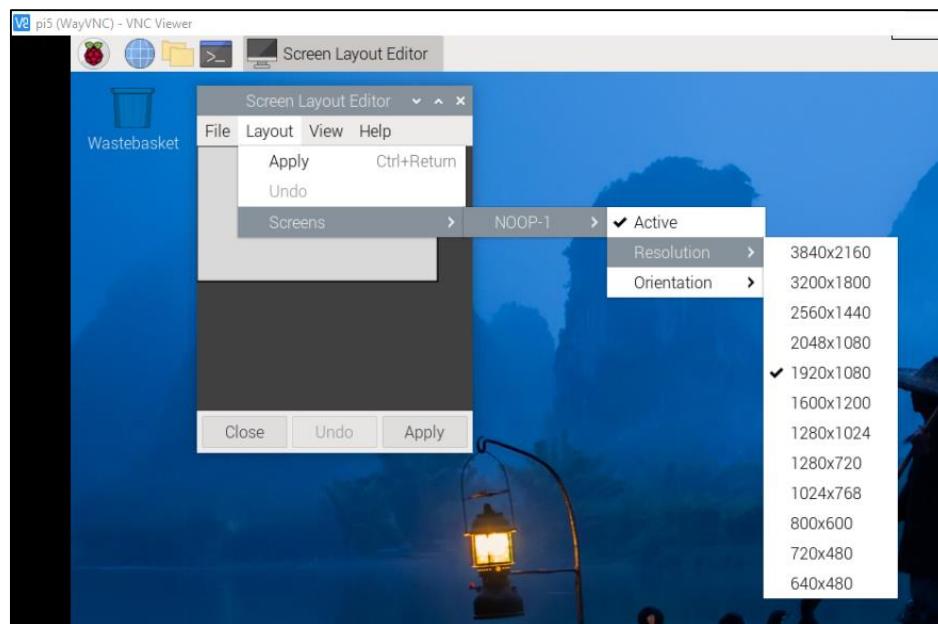
Here, you have logged in to Raspberry Pi successfully by using VNC Viewer

## Set Resolution

You can also set other resolutions.

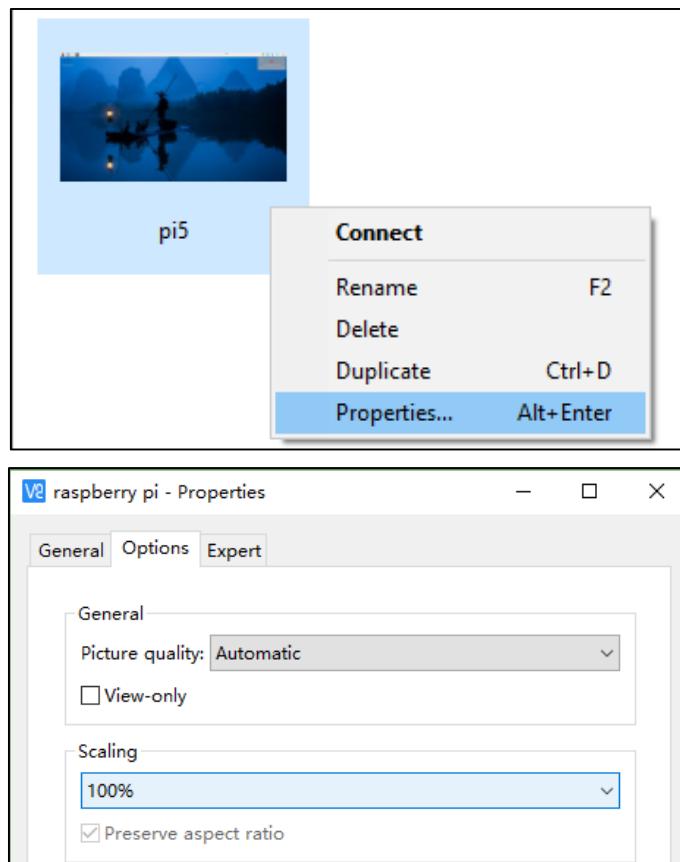


If you don't know what resolution to set properly, you can try 1920x1080.

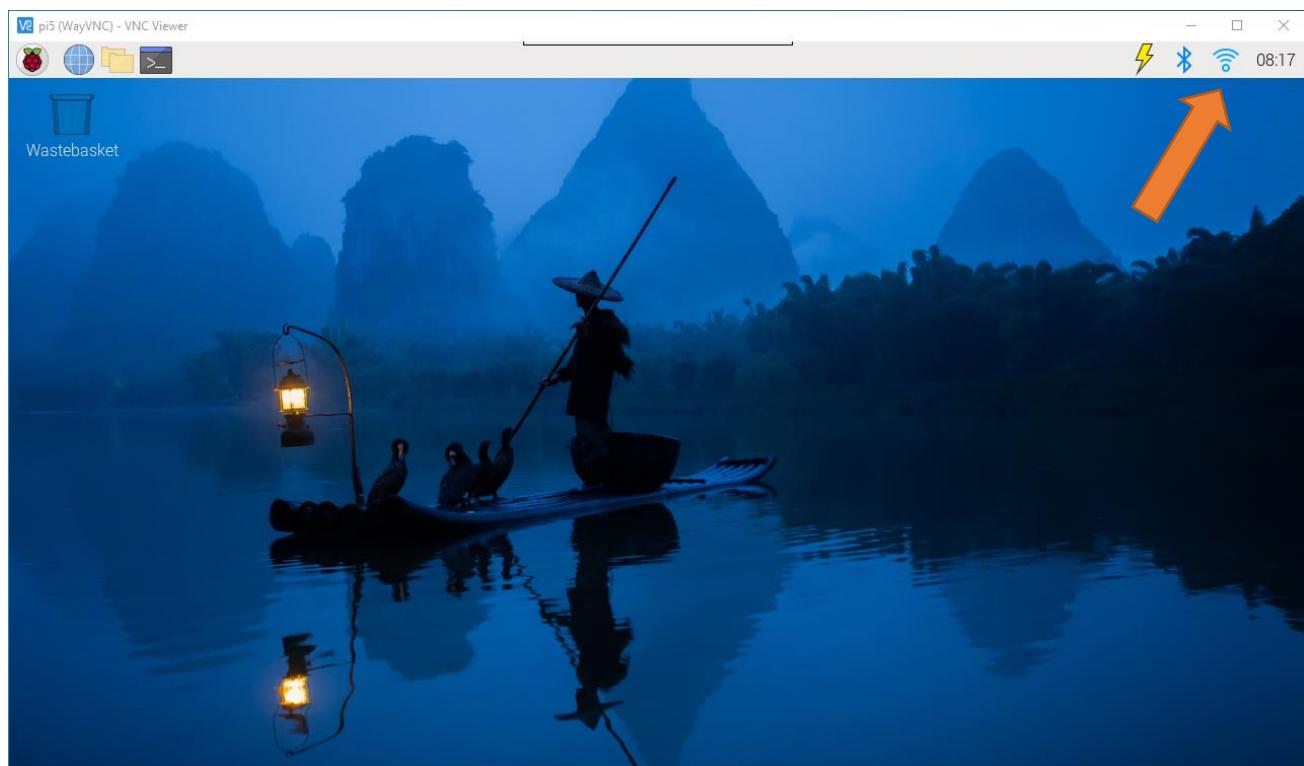




In addition, your VNC Viewer window may zoom your Raspberry Pi desktop. You can change it. On your VNC View control panel, click right key. And select Properties->Options label->Scaling. Then set proper scaling.



Here, you have logged in to Raspberry Pi successfully by using VNC Viewer and operated proper setting. Raspberry Pi 5/4B/3B+/3B integrates a Wi-Fi adaptor. If you did not connect Pi to WiFi. You can connect it to wirelessly control the robot.



# Chapter 0 Preparation

Pi4J is a Java I/O library specially designed for Raspberry Pi platform.

The Pi4J project aims to provide Java programs with access, control and communication to the core I/O functions of the Raspberry Pi, enabling Java programmers to easily access and control the full I/O capabilities of the Raspberry Pi platform. It abstracts the low-level native integration and interrupt monitoring to enable Java programmers to focus on implementing their application business logic.

It is recommended to use JBang to run pi4j code. JBang allows you to execute Java code with dependencies as a single file without the need for a full Maven or Gradle project. You also don't need to compile your code. So it's a very easy way to get started with Java and Pi4J.

<https://www.pi4j.com/examples/jbang/>

To learn more about Pi4J, please refer to the documentation linked below:

<https://www.pi4j.com/documentation/>

## Download Code

Run the following command to download the code to Raspberry Pi.

```
cd ~  
git clone --depth 1 https://github.com/Freenove/Freenove\_Projects\_Kit\_for\_Raspberry\_Pi.git
```

Run the command to rename the folder.

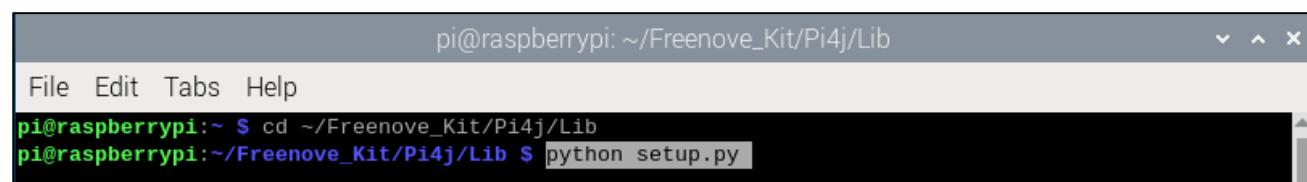
```
mv Freenove_Projects_Kit_for_Raspberry_Pi/ Freenove_Kit/
```

## Installation of JBang

Run the following commands one by one to install jbang.

```
cd ~/Freenove_Kit/Pi4j/Lib  
python setup.py
```

Please note that sudo is not applicable here.



```
pi@raspberrypi:~/Freenove_Kit/Pi4j/Lib  
File Edit Tabs Help  
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Lib  
pi@raspberrypi:~/Freenove_Kit/Pi4j/Lib $ python setup.py
```

The built-in default-jdk library is not complete, so we need to uninstall and reinstall it.

Enter 'Y' to uninstall it.

```
The following packages will be REMOVED:
 default-jdk* default-jdk-headless* default-jre* default-jre-headless*
 openjdk-17-jdk* openjdk-17-jdk-headless* openjdk-17-jre* openjdk-17-jre-headless*
0 upgraded, 0 newly installed, 8 to remove and 214 not upgraded.
After this operation, 275 MB disk space will be freed.
Do you want to continue? [Y/n] ■
```

Enter 'Y' again to install the full default-jdk library.

```
The following NEW packages will be installed:
 default-jdk default-jdk-headless default-jre default-jre-headless openjdk-17-jdk
 openjdk-17-jdk-headless openjdk-17-jre openjdk-17-jre-headless
0 upgraded, 8 newly installed, 0 to remove and 214 not upgraded.
Need to get 0 B/116 MB of archives.
After this operation, 275 MB of additional disk space will be used.
Do you want to continue? [Y/n] ■
```

When you see the messages below, it indicates that the installation is almost finished.

You can run the following commands one by one to check whether jbang is installed.

```
source ~/.bashrc
jbang --version
```

```
Successfully extracted and moved contents of jbang-0.119.0.tar to /home/pi/.jbang
Added export PATH="$HOME/.jbang/bin:$PATH" to /home/pi/.bashrc

Please run the following command in your terminal to update your PATH:
1, source ~/.bashrc
2, jbang --version
pi@raspberrypi:~/Freenove_Kit/Pi4j/Lib $ source ~/.bashrc
pi@raspberrypi:~/Freenove_Kit/Pi4j/Lib $ jbang --version
0.119.0
pi@raspberrypi:~/Freenove_Kit/Pi4j/Lib $ ■
```

When you see the results as above, it means that jbang is already installed.

## Installation of Geany

Geany is installed on Raspberry Pi OS by default.

You can run the following command to see if Geany is installed.

```
geany --version
```

If geany is not installed on your OS, please run the following command to install it.

```
sudo apt-get install geany
```

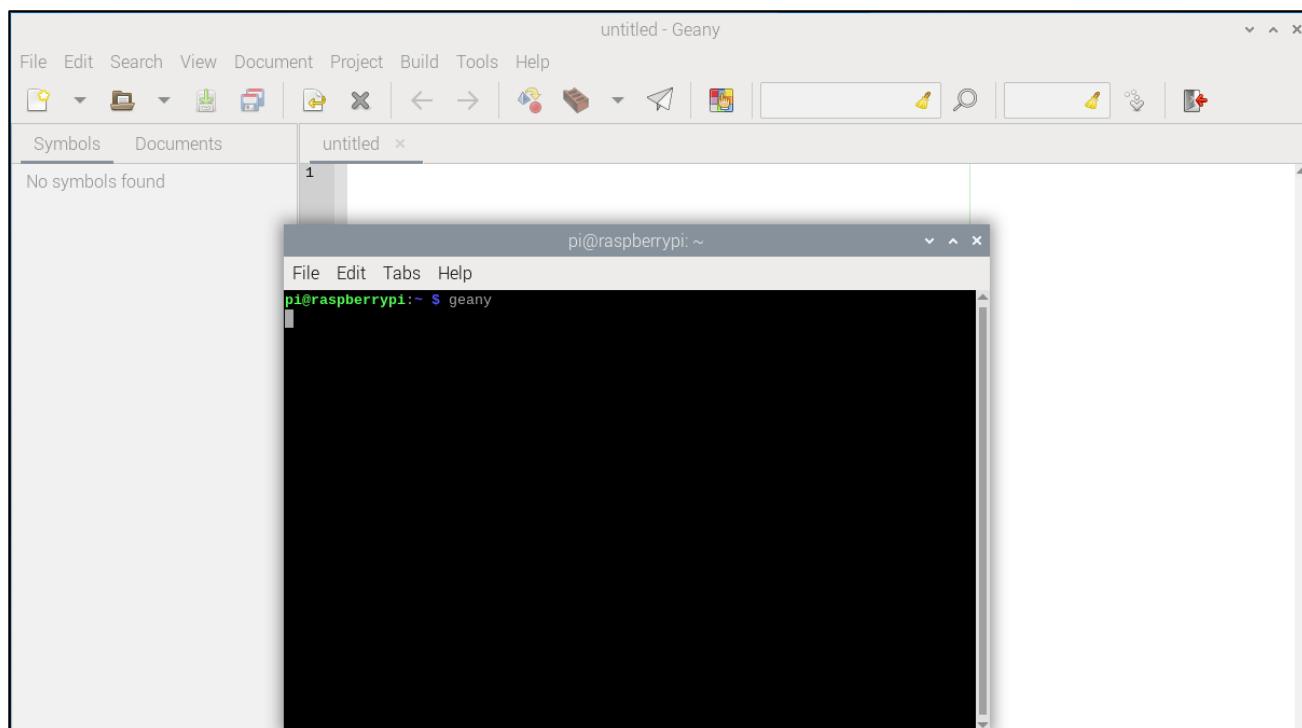
```
pi@raspberrypi:~ $ geany --version
bash: geany: command not found
pi@raspberrypi:~ $ sudo apt-get install geany
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
■
```

## Geany Configuration

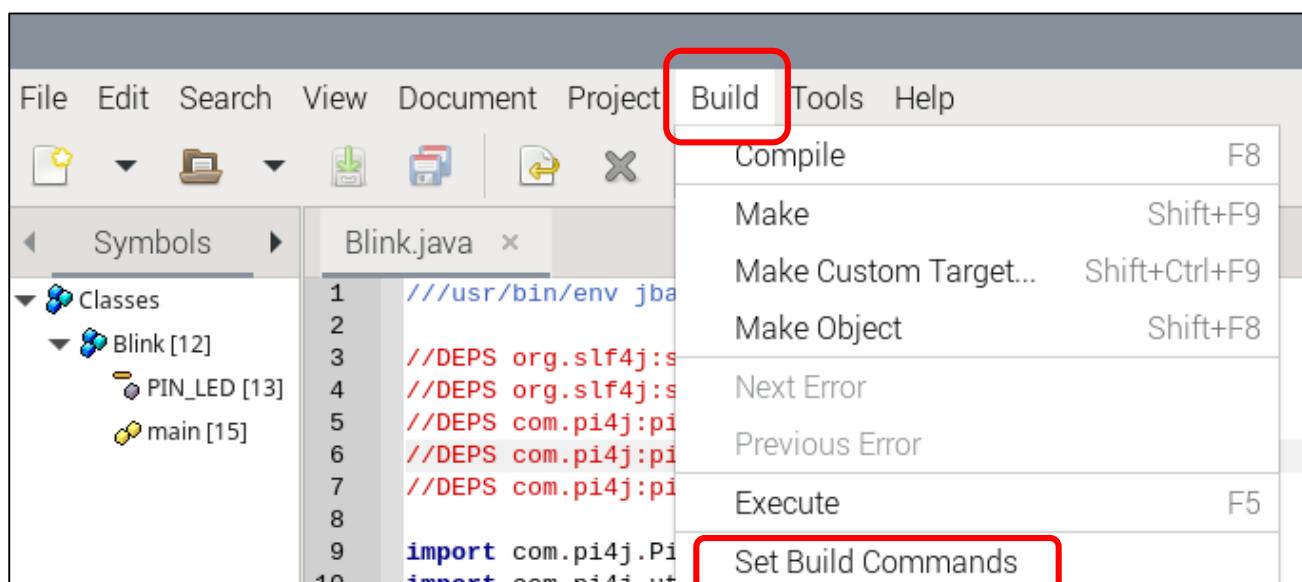
Run the command to open Geany software.

```
geany
```

As can be seen below, Geany is open after the command is run.



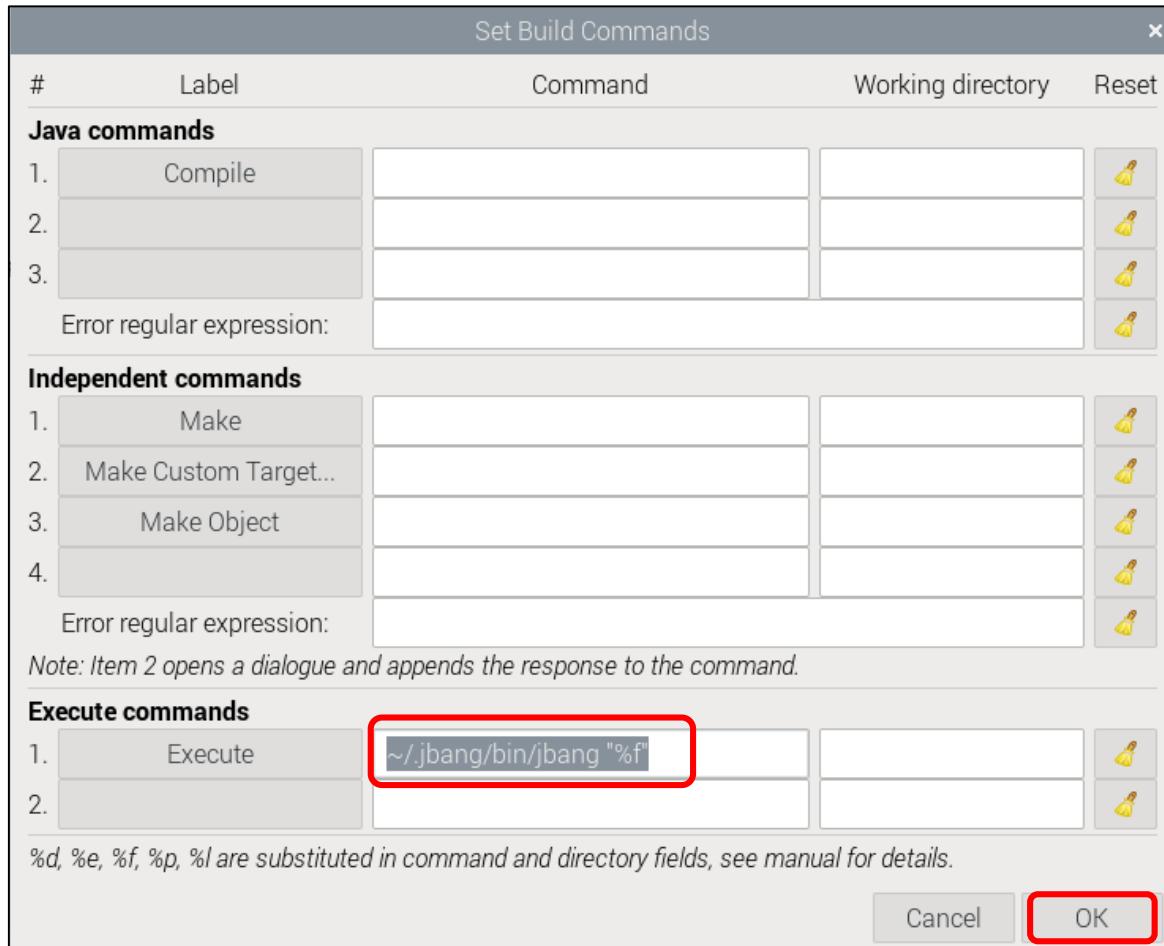
Click Build -> Set Build Commands on the menu bar.



In the pop-up window, enter the following command.

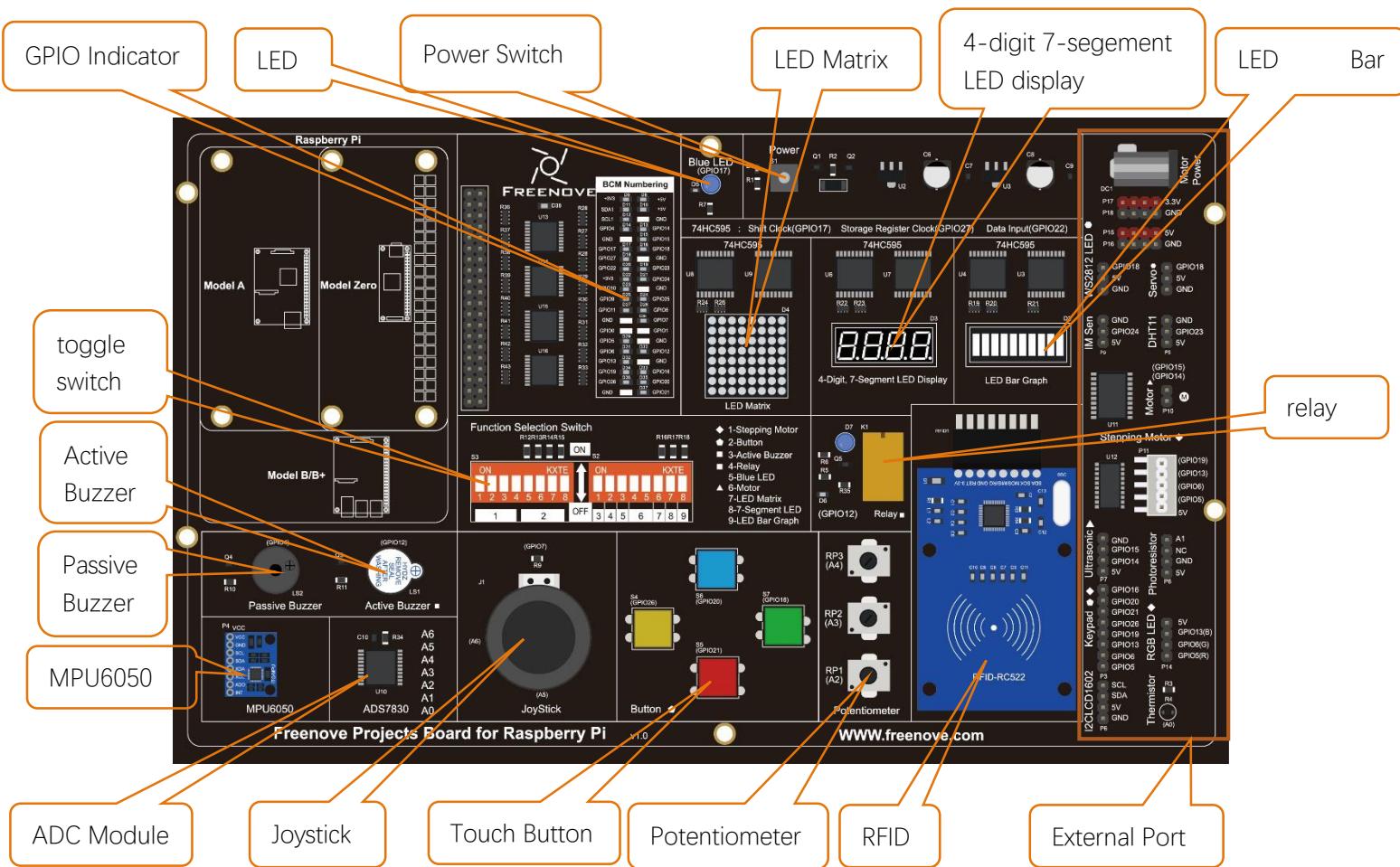
**~/.jbang/bin/jbang "%f"**

The detailed operation is as illustrated below:



So far, you can use Geany to open, edit, and run the code of the Pi4J tutorial.

## Projects Board for Raspberry Pi



### Note:

1. Stepper motor, keypad and RGBLED must NOT be used at the same time.
2. Touch button and keypad must NOT be used at the same time.
3. Active buzzer and relay must NOT be used at the same time.
4. Motor and ultrasonic module must NOT be used at the same time.
5. Servo and WS2812LED must NOT be used at the same time.
6. Batteries need to be plugged in when using the motor.

# Chapter 1 LED

We will still start from Blink LED in this chapter, and learn the usage of some commonly used functions of Processing Software.

## Project 1.1 Blink

In this project, we will use Pi4J to control the Raspberry Pi's GPIO, so as to control the LED to blink.

### GPIO

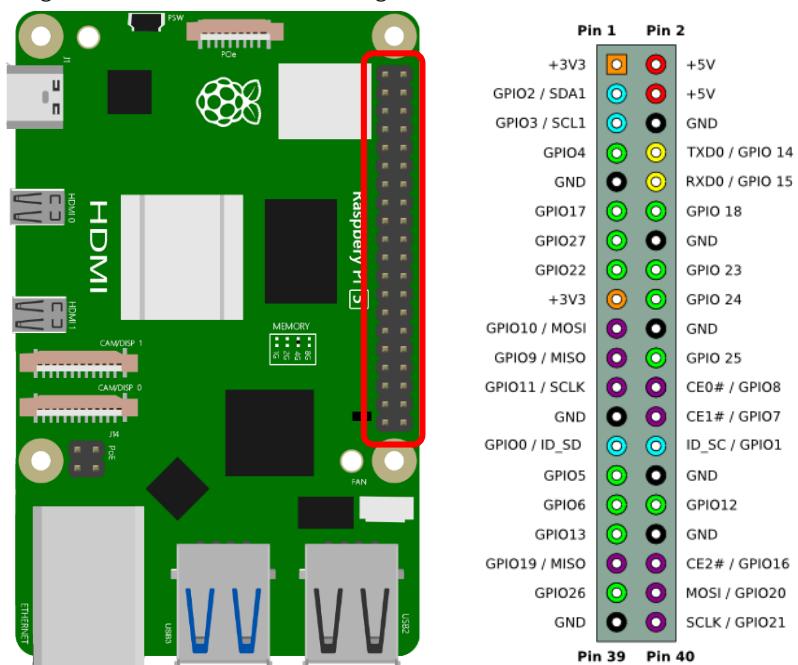
GPIO: General Purpose Input/Output. Here we will introduce the specific function of the pins on the Raspberry Pi and how you can utilize them in all sorts of ways in your projects. Most RPi Module pins can be used as either an input or output, depending on your program and its functions.

When programming GPIO pins, there are 3 different ways to reference them: GPIO Numbering, Physical Numbering and WiringPi GPIO Numbering.

#### BCM GPIO Numbering

The Raspberry Pi CPU uses Broadcom (BCM) processing chips BCM2835, BCM2836 or BCM2837. GPIO pin numbers are assigned by the processing chip manufacturer and are how the computer recognizes each pin. The pin numbers themselves do not make sense or have meaning, as they are only a form of identification. Since their numeric values and physical locations have no specific order, there is no way to remember them, so you will need to have a printed reference or a reference board that fits over the pins.

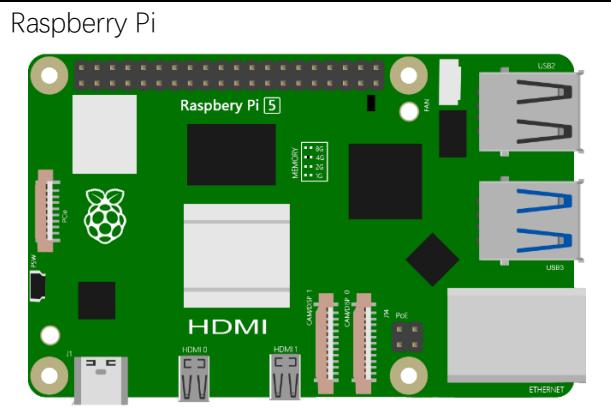
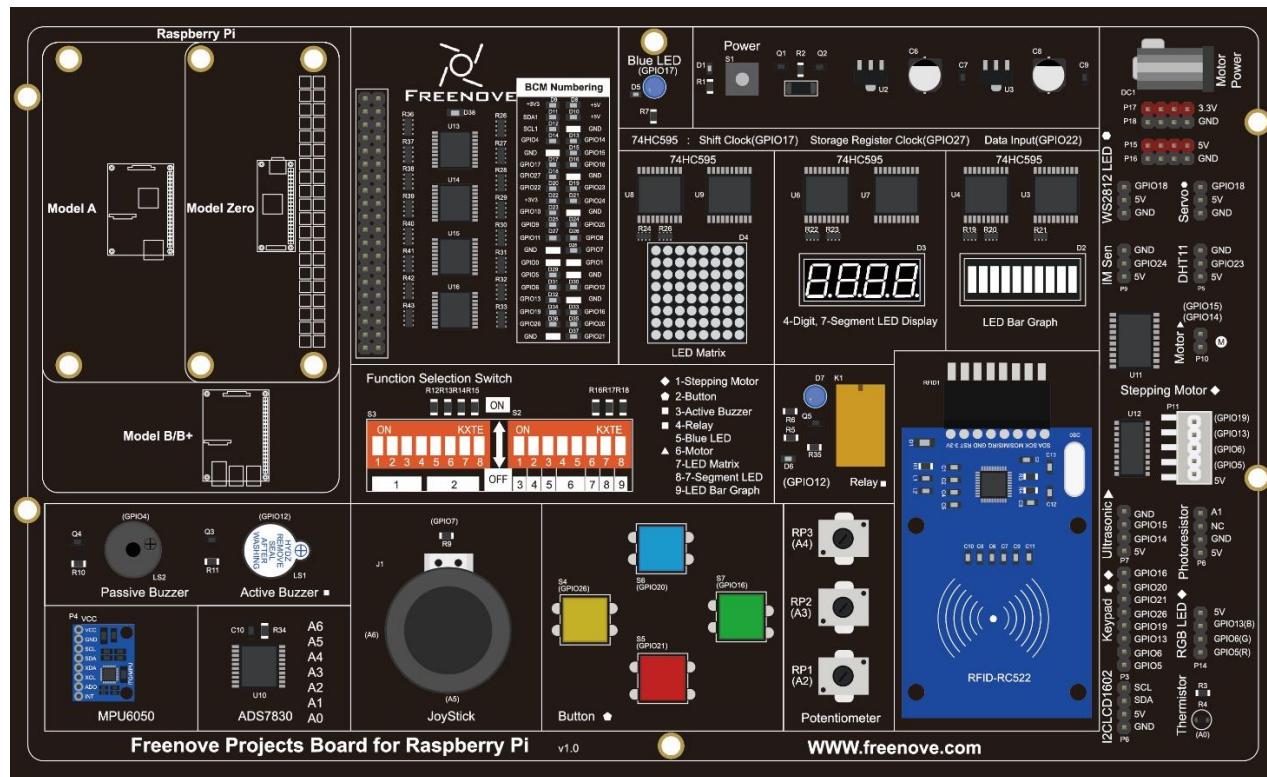
Each pin's functional assignment is defined in the image below:



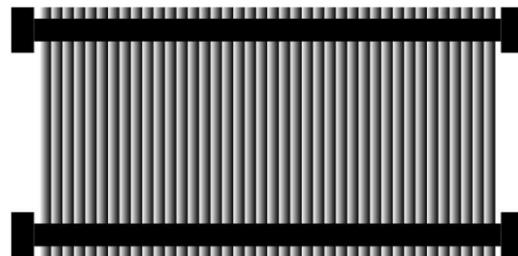
For more details about pin definition of GPIO, please refer to <http://pinout.xyz/>

## Component List

Freenove Projects Board for Raspberry Pi

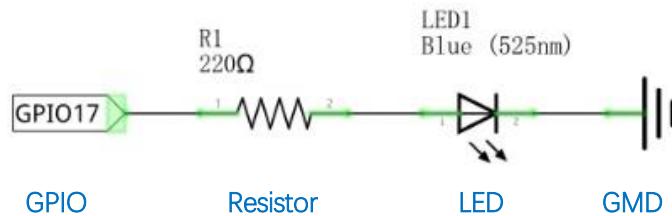


GPIO Ribbon Cable



## Circuit

Schematic diagram

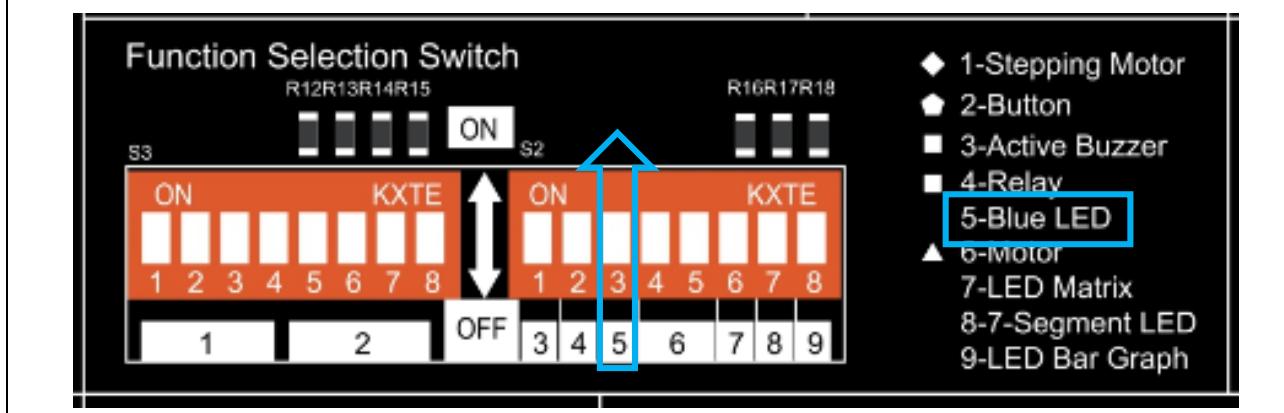
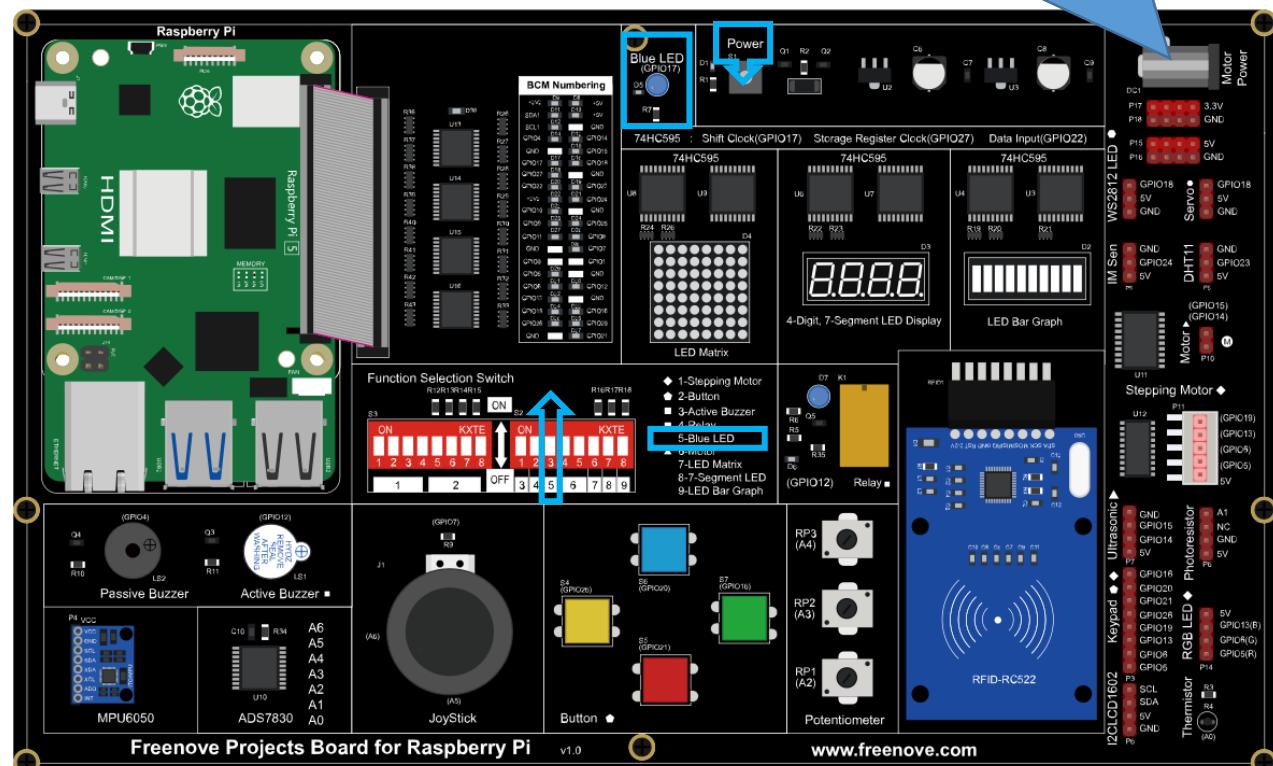


Hardware connection:

Turn ON the power switch and NO.5 toggle switch.

Power switch should be turned ON in all the projects.

It will be introduced when it is needed.



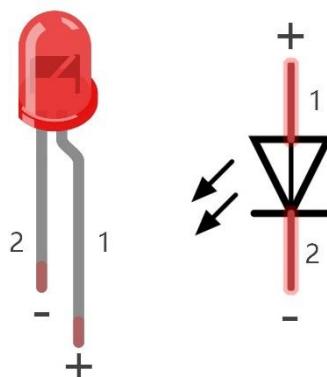
If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Component knowledge

### LED

An LED is a type of diode. All diodes have two Poles and only work if current is flowing in the correct direction. An LED will only work (light up) if the longer pin (+) of LED is connected to the positive output from a power source and the shorter pin is connected to the negative (-) output, which is also referred to as Ground (GND). This type of component is known as "Polar" (think One-Way Street).

All common 2 lead diodes are the same in this respect. Diodes work only if the voltage of its positive electrode is higher than its negative electrode and there is a narrow range of operating voltage for most all common diodes of 1.9 and 3.4V. If you use much more than 3.3V the LED will be damaged and burnt out.



LED	Voltage	Maximum current	Recommended current
Red	1.9 - 2.2V	20mA	10mA
Green	2.9 - 3.4V	10mA	5mA
Blue	2.9 - 3.4V	10mA	5mA
Volt ampere characteristics conform to diode			

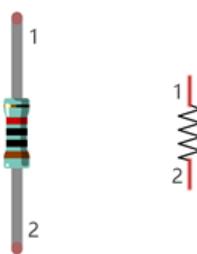
Note: LEDs cannot be directly connected to a power supply, which usually ends in a damaged component. A resistor with a specified resistance value must be connected in series to the LED you plan to use.

### Resistor

Resistors use Ohms ( $\Omega$ ) as the unit of measurement of their resistance (R).  $1M\Omega=1000k\Omega$ ,  $1k\Omega=1000\Omega$ .

A resistor is a passive electrical component that limits or regulates the flow of current in an electronic circuit.

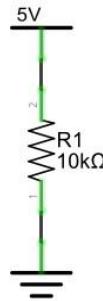
On the left, we see a physical representation of a resistor, and the right is the symbol used to represent the presence of a resistor in a circuit diagram or schematic.



The bands of color on a resistor is a shorthand code used to identify its resistance value. For more details of resistor color codes, please refer to the card in the kit package.

With a fixed voltage, there will be less current output with greater resistance added to the circuit. The relationship between Current, Voltage and Resistance can be expressed by this formula:  $I=V/R$  known as Ohm's Law where I = Current, V = Voltage and R = Resistance. Knowing the values of any two of these allows you to solve the value of the third.

In the following diagram, the current through R1 is:  $I=U/R=5V/10k\Omega=0.0005A=0.5mA$ .



**WARNING:** Never connect the two poles of a power supply with anything of low resistance value (i.e. a metal object or bare wire). This is a Short and results in high current that may damage the power supply and electronic components.

Note: Unlike LEDs and Diodes, Resistors have no poles and are non-polar (it does not matter which direction you insert them into a circuit, it will work the same)

## Sketch

According to the circuit, when the GPIO17 of Raspberry Pi output level is high, the LED turns ON. Conversely, when the GPIO17 Raspberry Pi output level is low, the LED turns OFF. Therefore, we can let GPIO17 cycle output high and output low level to make the LED blink.

### Sketch\_01\_Blink

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_01_Blink
```

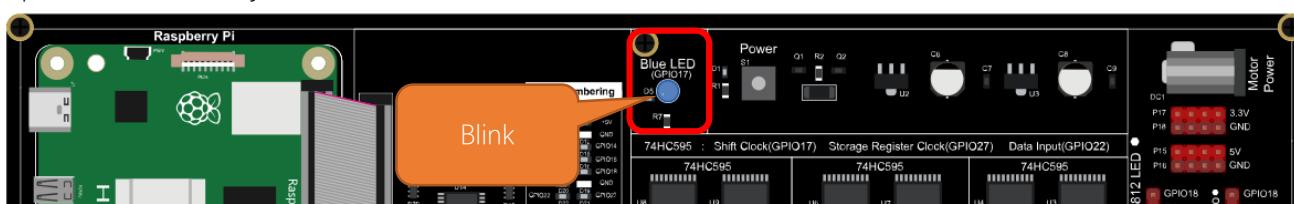
```
pi@raspberrypi:~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_01_Blink/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_01_Blink $
```

Enter the command to run the code.

```
jbang Blink.java
```

```
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_01_Blink $ jbang Blink.java
```

Upon the code runs, you can see the onboard blue LED blinks.



And on Raspberry Pi Terminal, you can see the corresponding messages printed.

```
[main] INFO com.pi4j.util.Console - LED low
[main] INFO com.pi4j.util.Console - LED high
[main] INFO com.pi4j.util.Console - LED low
[main] INFO com.pi4j.util.Console - LED high
```

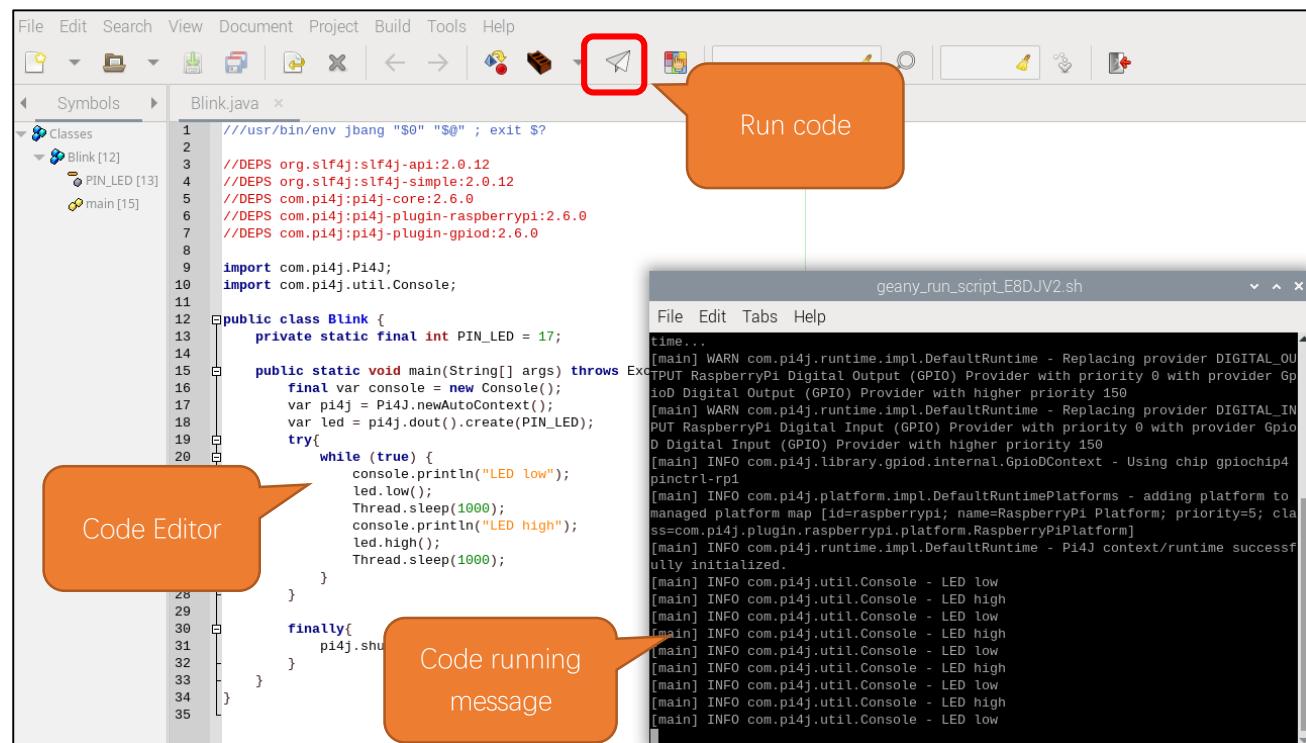
Press CTRL-C to exit the program.

```
[main] INFO com.pi4j.util.Console - LED low
[main] INFO com.pi4j.util.Console - LED high
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown.
Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_01_Blink $
```

If you want to view or modify the code, you can open the code with Geany with the following command.

**geany Blink.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.util.Console;
11
12 public class Blink {
13     private static final int PIN_LED = 17;
14
15     public static void main(String[] args) throws Exception {
16         final var console = new Console();
17         var pi4j = Pi4J.newAutoContext();
18         var led = pi4j.dout().create(PIN_LED);
19
20         try{
21             while (true) {
22                 console.println("LED low");
23                 led.low();
24                 Thread.sleep(1000);
25                 console.println("LED high");
26                 led.high();
27                 Thread.sleep(1000);
28             }
29         } finally{
30             pi4j.shutdown();
31         }
32     }
33 }
34

```

```

21         console.println("LED low");
22         led.low();
23         Thread.sleep(1000);
24         console.println("LED high");
25         led.high();
26         Thread.sleep(1000);
27     }
28 }
29 finally{
30     pi4j.shutdown();
31 }
32 }
33 }
```

At the beginning of the code, we use shebang command to inform Raspberry Pi that we are going to use JBang to run Java script.

```
//usr/bin/env jbang "$0" "$@" ; exit $?
```

Likewise, we specify the dependencies required for the script to run. This includes the different components of the SLF4J logging library and the Pi4J library and their version numbers.

```

//DEPS org.slf4j:slf4j-api:2.0.12
//DEPS org.slf4j:slf4j-simple:2.0.12
//DEPS com.pi4j:pi4j-core:2.6.0
//DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
//DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
```

Import Pi4J library and the Console class to facilitate creating and managing contexts and printing messages on the console.

```

import com.pi4j.Pi4J;
import com.pi4j.util.Console;
```

Assign the GPIO pin to the LED, and configure it as output mode.

```

private static final int PIN_LED = 17;

public static void main(String[] args) throws Exception {
    final var console = new Console();
    var pi4j = Pi4J.newAutoContext();
    var led = pi4j.dout().create(PIN_LED);
```

Use the try···finally structure to ensure the smooth running of the code.

```

try{

}
finally{

}
```

Make the LED turn on and off once every 1 second, repeat this process, and print prompt messages.

```
while (true) {  
    console.println("LED low"); // Print a prompt message on the terminal  
    led.low(); // turn off led  
    Thread.sleep(1000); // delay 1 second  
    console.println("LED high"); // Print a prompt message on the terminal  
    led.high(); // turn on led  
    Thread.sleep(1000); // delay 1 second  
}
```

# Chapter 2 Flowing Light

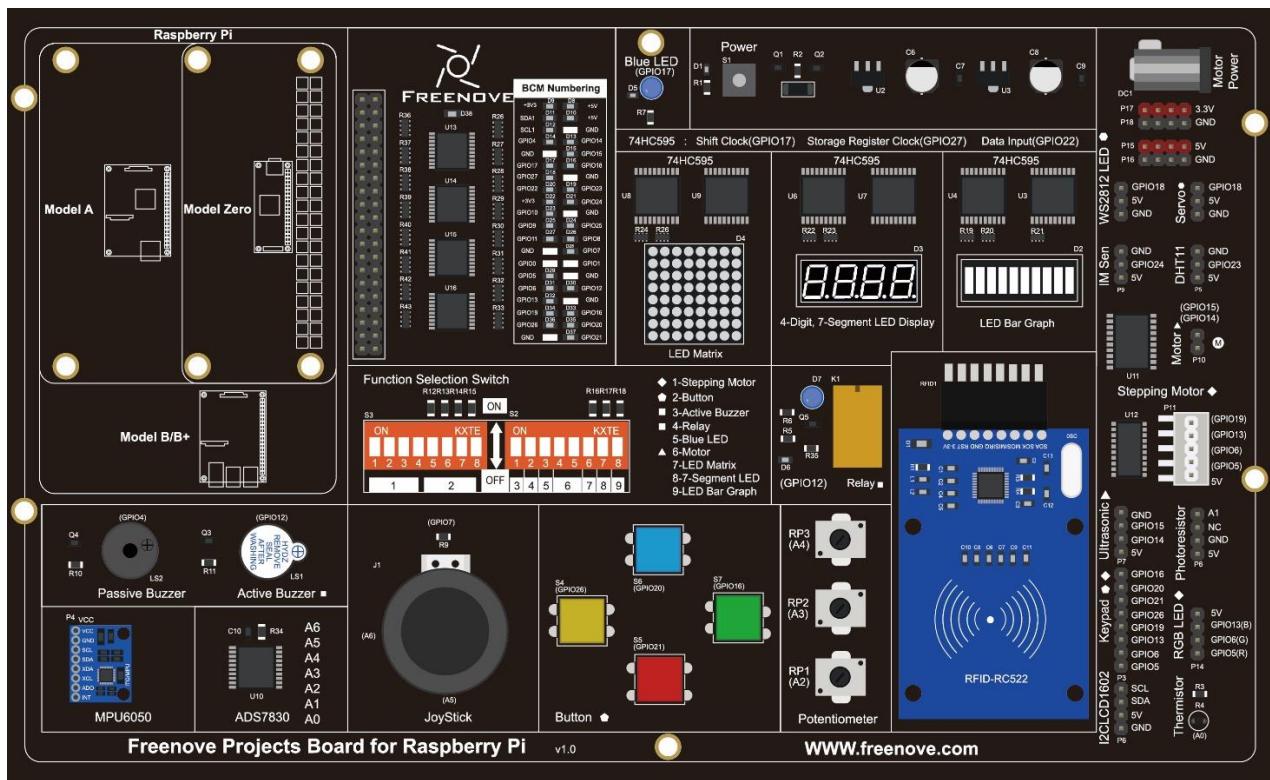
We have learned how to control one LED to blink. Next, we will learn how to control a number of LEDs.

## Project 2.1 Flowing Water Light

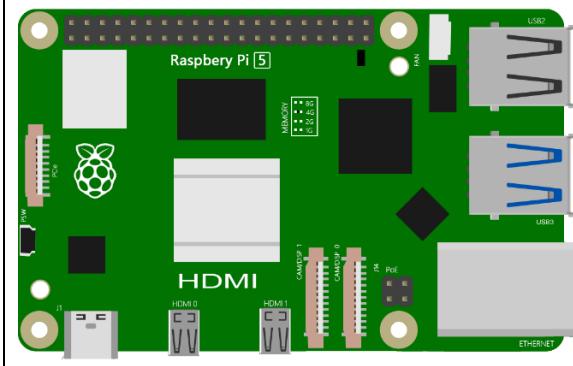
In this project, we use a number of LEDs to make a flowing water light.

### Component List

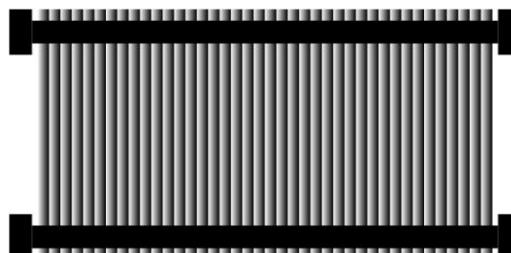
Freenove Projects Board for Raspberry Pi



Raspberry Pi

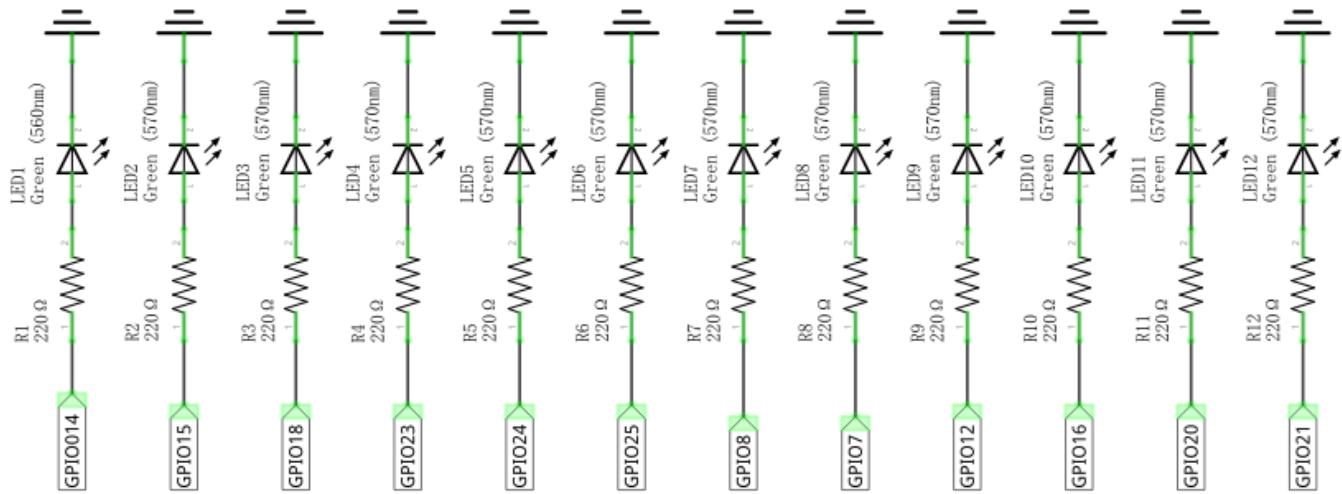


GPIO Ribbon Cable

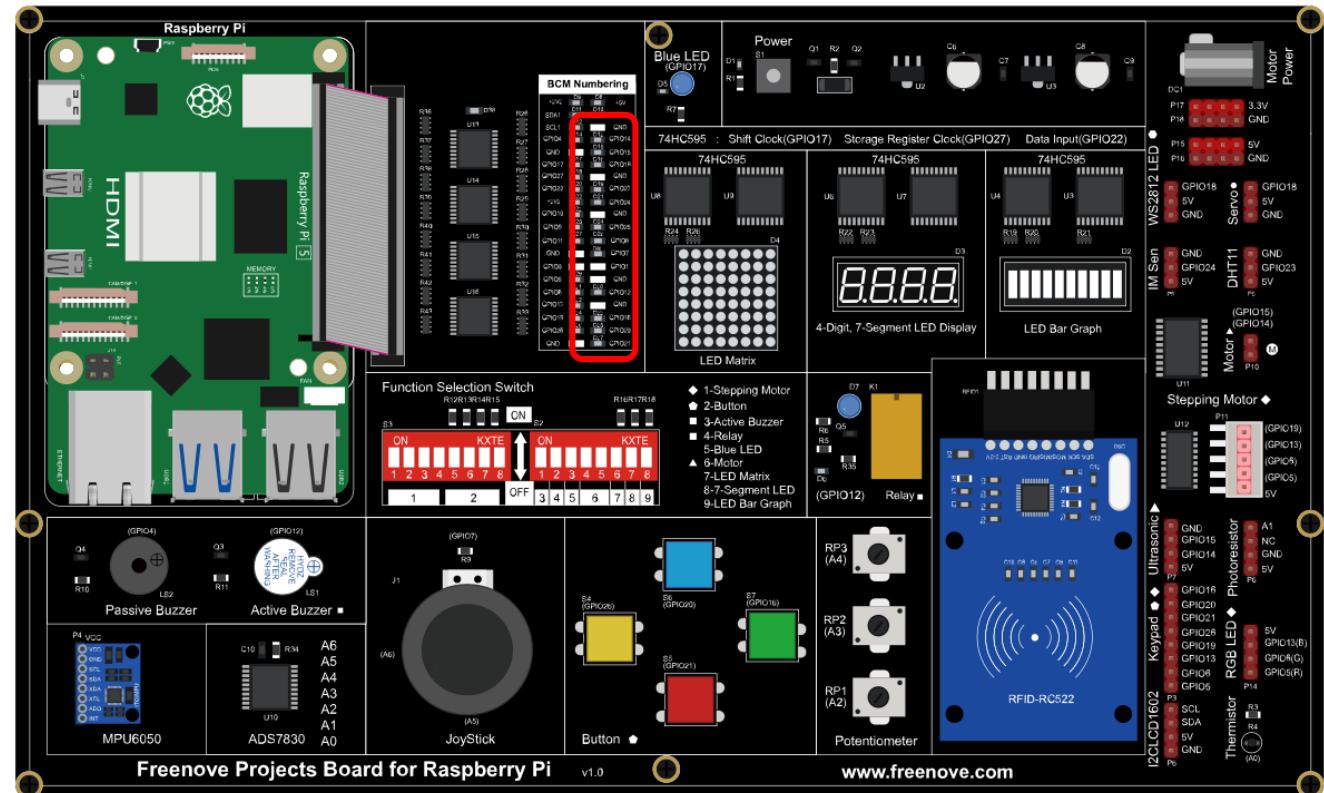


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In this chapter, we will introduce how to control multiple LEDs with various GPIOs, and make the LEDs present a flowing effect.

### Sketch\_02\_FlowingLight

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_02_FlowingLight
```

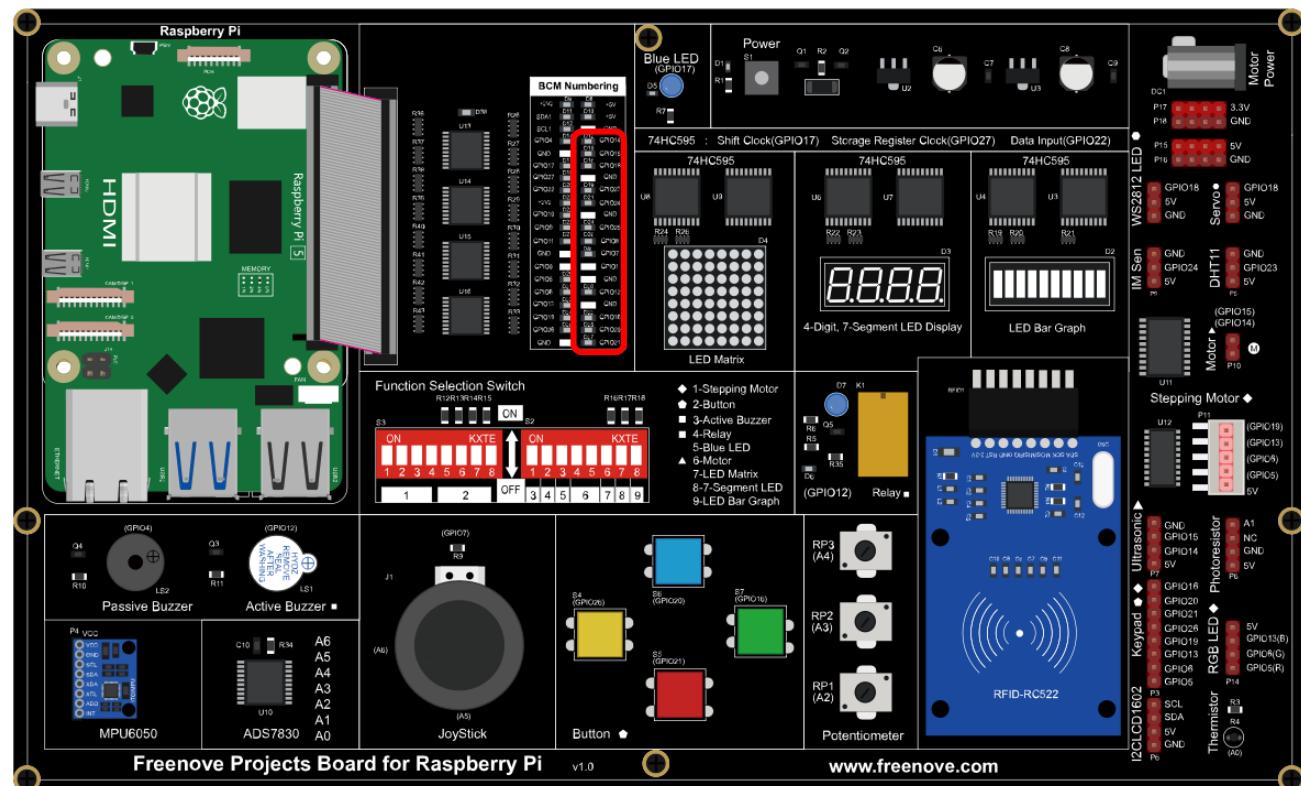
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_02_FlowingLight
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_02_FlowingLight $
```

Enter the command to run the code.

```
jbang FlowingLight.java
```

```
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_02_FlowingLight $ jbang FlowingLight.java
```

When the code is running, you can see the onboard indicators lights up in a flowing effect.



On the Raspberry Pi Terminal, you can see messages printed.

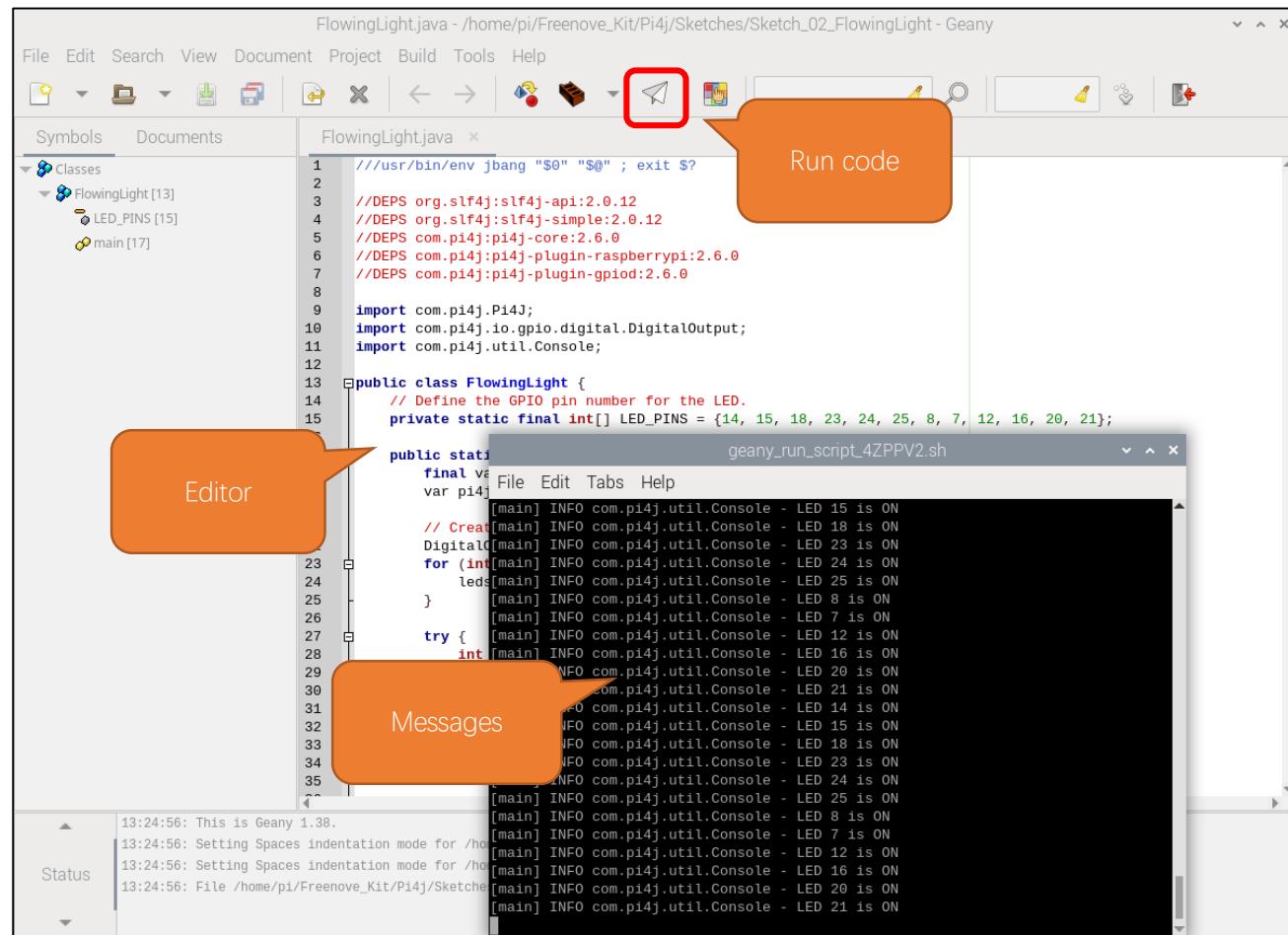
```
[main] INFO com.pi4j.util.Console - LED 23 is ON
[main] INFO com.pi4j.util.Console - LED 24 is ON
[main] INFO com.pi4j.util.Console - LED 25 is ON
[main] INFO com.pi4j.util.Console - LED 8 is ON
[main] INFO com.pi4j.util.Console - LED 7 is ON
[main] INFO com.pi4j.util.Console - LED 12 is ON
[main] INFO com.pi4j.util.Console - LED 16 is ON
[main] INFO com.pi4j.util.Console - LED 20 is ON
[main] INFO com.pi4j.util.Console - LED 21 is ON
[main] INFO com.pi4j.util.Console - LED 14 is ON
[main] INFO com.pi4j.util.Console - LED 15 is ON
[main] INFO com.pi4j.util.Console - LED 18 is ON
```

Press CTRL+C to exit the code.

You can view and edit the code with Geany by running the following command.

**geany FlowingLight.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.io.gpio.digital.DigitalOutput;
11 import com.pi4j.util.Console;
12
13 public class FlowingLight {
    // Define the GPIO pin number for the LED.
    private static final int[] LED_PINS = {14, 15, 18, 23, 24, 25, 8, 7, 12, 16, 20, 21};
    ...
}
```

```

14 // Define the GPIO pin number for the LED.
15 private static final int[] LED_PINS = {14, 15, 18, 23, 24, 25, 8, 7, 12, 16, 20, 21};
16
17 public static void main(String[] args) throws Exception {
18     final var console = new Console();
19     var pi4j = Pi4J.newAutoContext();
20
21     DigitalOutput[] leds = new DigitalOutput[LED_PINS.length];
22     for (int i = 0; i < LED_PINS.length; i++) {
23         leds[i] = pi4j.dout().create(LED_PINS[i]);
24     }
25
26     try {
27         int currentLed = 0;
28         while (true) {
29             console.println("LED " + LED_PINS[currentLed] + " is ON");
30             for (DigitalOutput led : leds) {
31                 led.low();
32             }
33             leds[currentLed].high();
34             Thread.sleep(100);
35             currentLed = (currentLed + 1) % LED_PINS.length;
36         }
37     } finally {
38         pi4j.shutdown();
39     }
40 }
41 }
```

Import the classes of Pi4J library for GPIO control and simple console output.

```

import com.pi4j.Pi4J;
import com.pi4j.io.gpio.digital.DigitalOutput;
import com.pi4j.util.Console;
```

Define an array that includes the GPIO numbers connecting to LEDs.

```

// Define the GPIO pin number for the LED.
private static final int[] LED_PINS = {14, 15, 18, 23, 24, 25, 8, 7, 12, 16, 20, 21};
```

Create a DigitalOutput array based on the GPIO array that controls the LEDs, and create a DigitalOutput instance for each pin.

```

DigitalOutput[] leds = new DigitalOutput[LED_PINS.length];
for (int i = 0; i < LED_PINS.length; i++) {
    leds[i] = pi4j.dout().create(LED_PINS[i]);
}
```

Iterate through all LEDs and turn them off (set to low level).

```
for (DigitalOutput led : leds) {  
    led.low();  
}
```

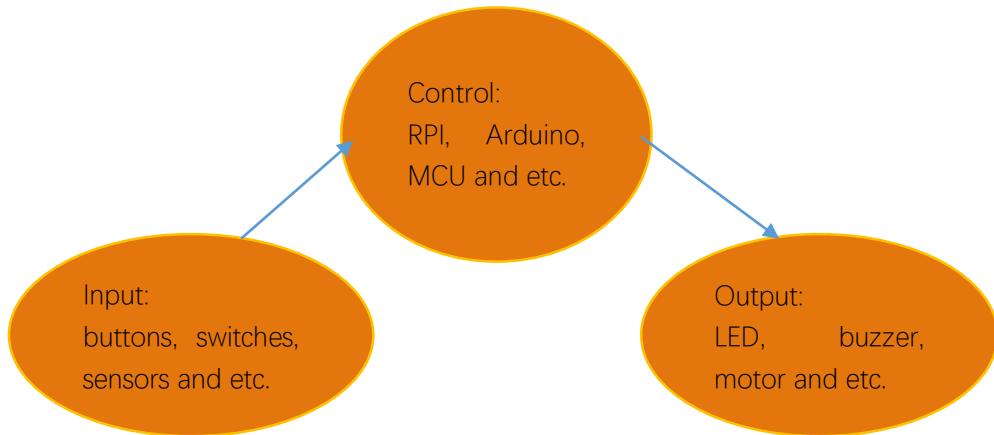
Use 'currentLed' to record the position of the LED that is lit, recalculate the position of the lit LED every 100 milliseconds, and print a prompt message to the console. At the same time, turn off all LEDs except the LED at the position recorded by 'currentLed'.

```
int currentLed = 0;  
while (true) {  
    console.println("LED " + LED_PINS[currentLed] + " is ON");  
    for (DigitalOutput led : leds) {  
        led.low();  
    }  
    leds[currentLed].high();  
    Thread.sleep(100);  
    currentLed = (currentLed + 1) % LED_PINS.length;  
}
```



# Chapter 3 Buttons & LEDs

Usually, there are three essential parts in a complete automatic control device: INPUT, OUTPUT, and CONTROL. In last section, the LED module was the output part and RPI was the control part. In practical applications, we not only make LEDs flash, but also make a device sense the surrounding environment, receive instructions and then take the appropriate action such as turn on LEDs, make a buzzer beep and so on.



Next, we will build a simple control system to control an LED through a push button switch.

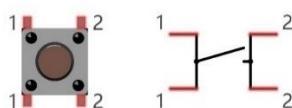
## Project 3.1 Push Button Switch & LED

In the project, we will control the LED state through a Push Button Switch. When the button is pressed, our LED will turn ON, and when it is released, the LED will turn OFF. This describes a Momentary Switch.

### Component knowledge

#### Push Button Switch

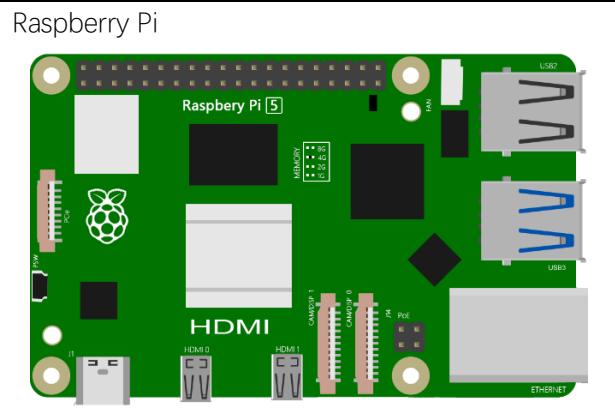
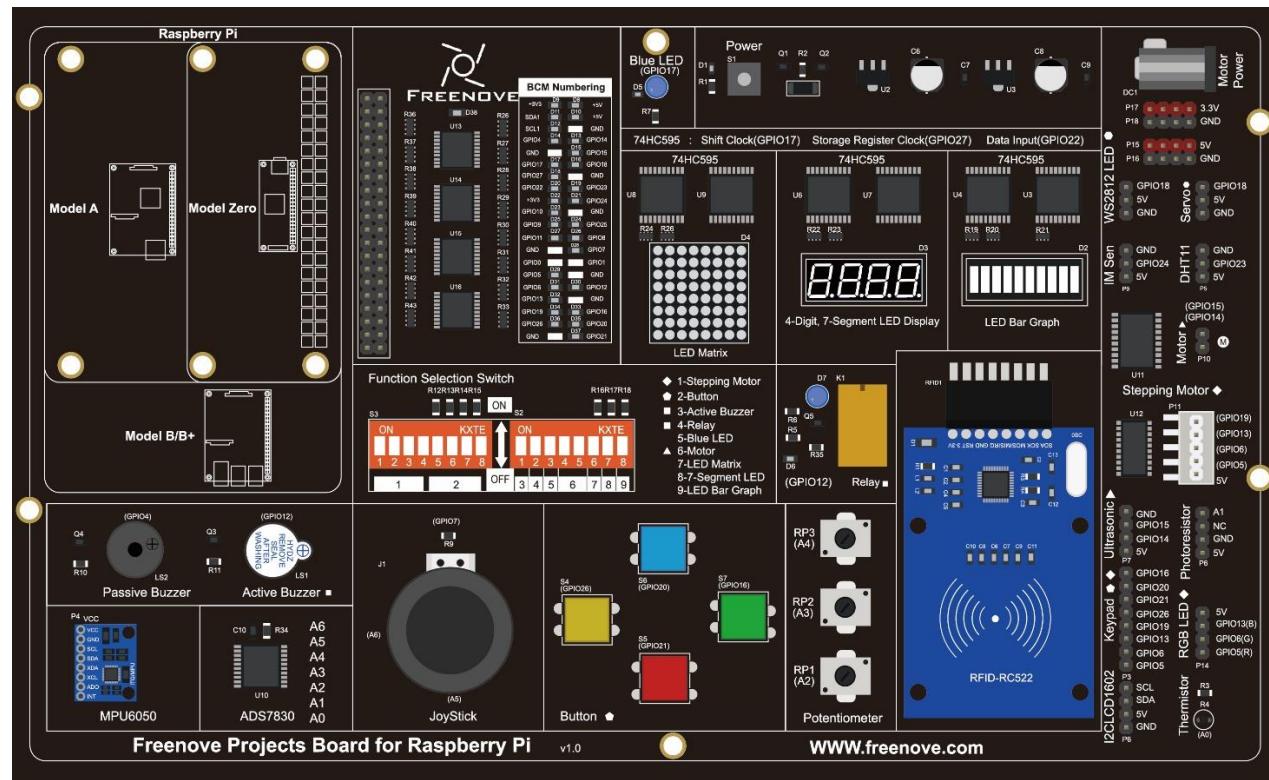
This type of Push Button Switch has 4 pins (2 Pole Switch). Two pins on the left are connected, and both left and right sides are the same as per the illustration:



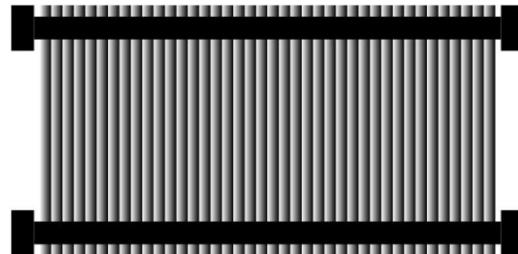
When the button on the switch is pressed, the circuit is completed (your project is Powered ON).

## Component List

Freenove Projects Board for Raspberry Pi

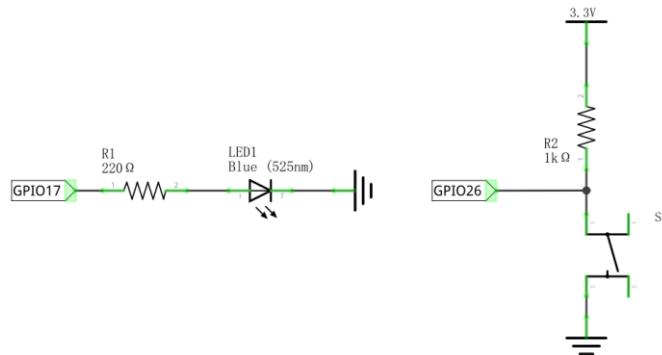


GPIO Ribbon Cable



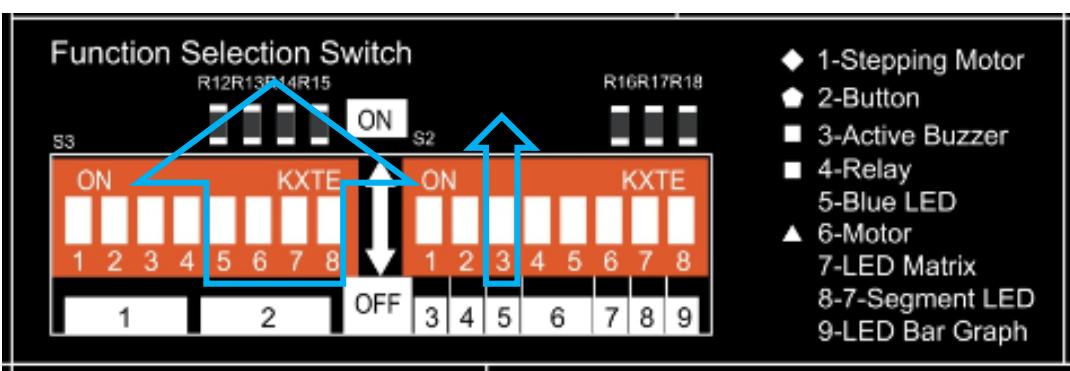
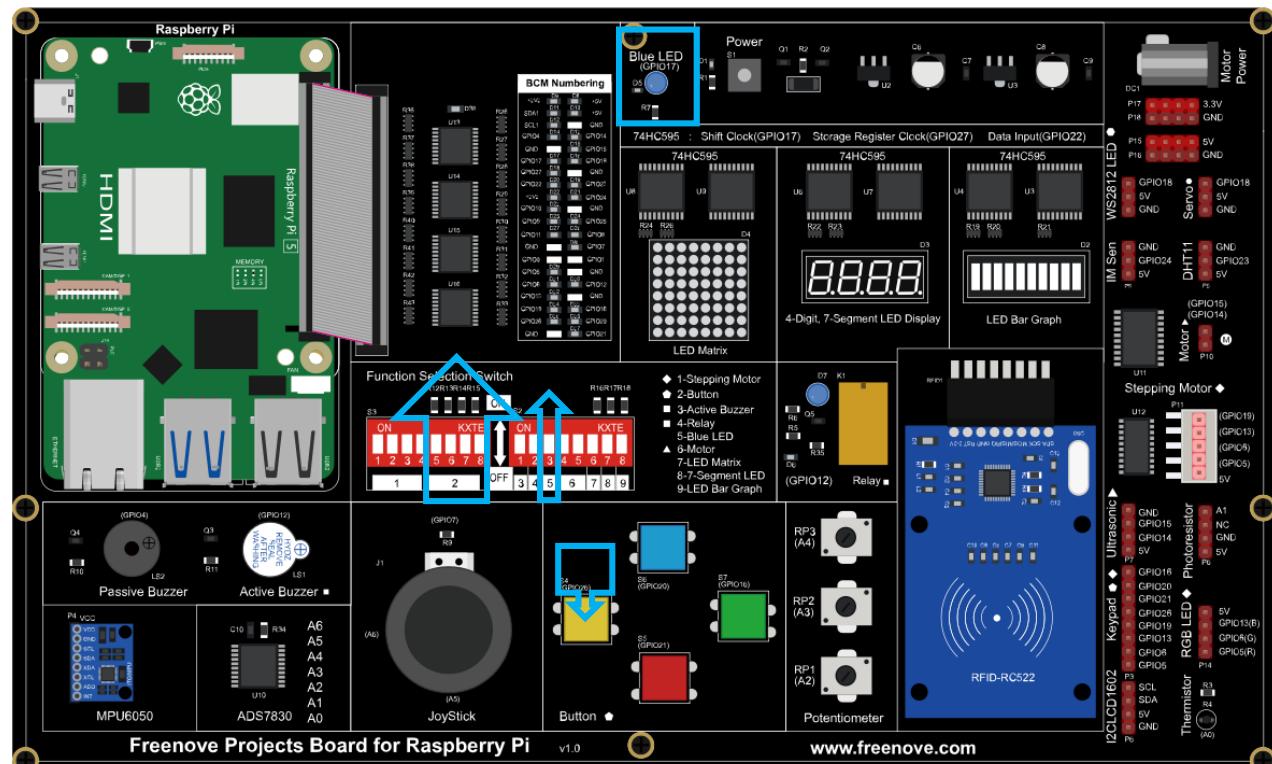
## Circuit

Schematic diagram



Hardware connection.

Switch ON NO.5 switch and the four switches of NO.2.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In this chapter, we will introduce how to use the button to control the LED.

### Sketch\_03\_ButtonLED

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_03_ButtonLED
```

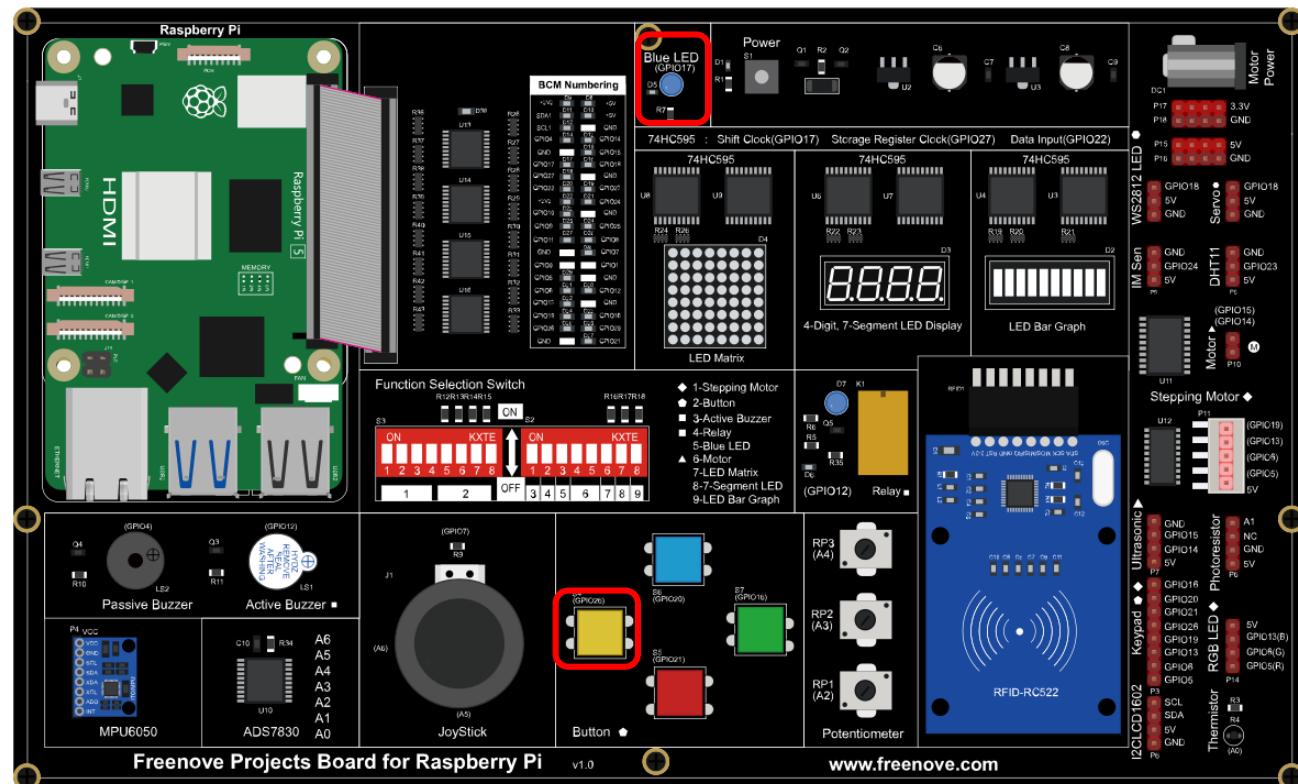
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_03_ButtonLED
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_03_ButtonLED $
```

Enter the command to run the code.

```
jbang ButtonLED.java
```

```
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_03_ButtonLED $ jbang ButtonLED.java
```

When the code is running, press the button and you can see the LED is lit; release it and the LED goes off.



On the Raspberry Pi terminal, you will see the corresponding messages printed.

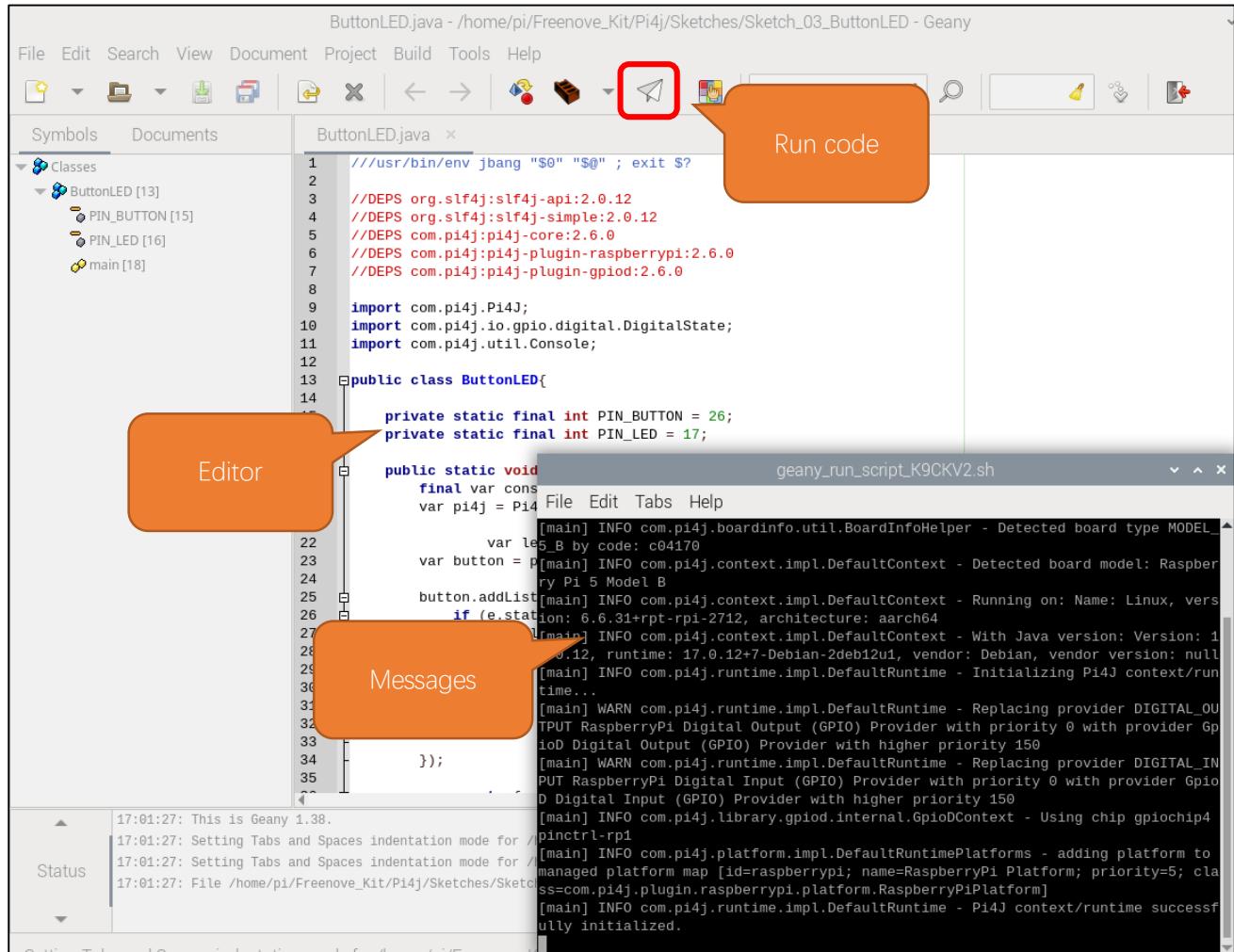
```
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Blue LED on.
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was released. Blue LED off.
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Blue LED on.
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was released. Blue LED off.
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Blue LED on.
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was released. Blue LED off.
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Blue LED on.
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was released. Blue LED off.
```

Press Ctrl+C to exit the code.

You can open the code with geany to view and edit it.

## geany ButtonLED.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.io.gpio.digital.DigitalState;
11 import com.pi4j.util.Console;
```

```

13 public class ButtonLED{
14
15     private static final int PIN_BUTTON = 26;
16     private static final int PIN_LED = 17;
17
18     public static void main(String[] args) throws Exception {
19         final var console = new Console();
20         var pi4j = Pi4J.newAutoContext();
21
22         var led = pi4j.dout().create(PIN_LED);
23         var button = pi4j.din().create(PIN_BUTTON);
24
25         button.addListener(e -> {
26             if (e.state() == DigitalState.LOW) {
27                 console.println("Button was pressed. Blue LED on.");
28                 led.high();
29             }
30             else if(e.state() == DigitalState.HIGH){
31                 console.println("Button was released. Blue LED off.");
32                 led.low();
33             }
34         });
35
36         try{
37             while (true) {
38                 Thread.sleep(500);
39             }
40         }
41         finally{
42             pi4j.shutdown();
43         }
44     }
45 }
```

Import the classes of Pi4J library for GPIO control and simple console output.

```

import com.pi4j.Pi4J;
import com.pi4j.io.gpio.digital.DigitalState;
import com.pi4j.util.Console;
```

Define the GPIO numbers for the button and LED.

```

private static final int PIN_BUTTON = 26;
private static final int PIN_LED = 17;
```



Create a Console instance for printing logs or messages.

Create a Pi4J context to manage the GPIO interface.

Create an LED output pin object, connected to the pin specified by PIN\_LED.

Create a button input pin object, connected to the pin specified by PIN\_BUTTON.

```
final var console = new Console();
var pi4j = Pi4J.newAutoContext();
var led = pi4j.dout().create(PIN_LED);
var button = pi4j.din().create(PIN_BUTTON);
```

Add a listener event to the button, which is triggered when the button's state changes.

When the button is pressed, its state is low, and we control the LED to light up.

When the button is released, its state is high, and we control the LED to turn off.

```
button.addListener(e -> {
    if (e.state() == DigitalState.LOW) {
        console.println("Button was pressed. Blue LED on.");
        led.high();
    }
    else if(e.state() == DigitalState.HIGH) {
        console.println("Button was released. Blue LED off.");
        led.low();
    }
});
```

Nothing needs to be done in the main loop. Just set it in an infinite loop and ensure that the Pi4J context is closed when the program ends.

```
try{
    while (true) {
        Thread.sleep(500);
    }
} finally{
    pi4j.shutdown();
}
```

# Chapter 4 Analog & PWM

In previous chapters, we learned that a Push Button Switch has two states: Pressed (ON) and Released (OFF), and an LED has a Light ON and OFF state. Is there a middle or intermediated state? We will next learn how to create an intermediate output state to achieve a partially bright (dim) LED.

First, let us learn how to control the brightness of an LED.

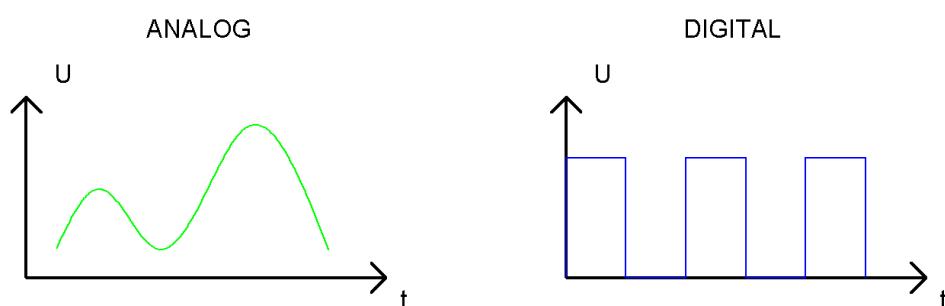
## Project 4.1 Breathing LED

We describe this project as a Breathing Light. This means that an LED that is OFF will then turn ON gradually and then gradually turn OFF like "breathing". Okay, so how do we control the brightness of an LED to create a Breathing Light? We will use PWM to achieve this goal.

## Component Knowledge

### Analog & Digital

An Analog Signal is a continuous signal in both time and value. On the contrary, a Digital Signal **or discrete-time signal is a time series consisting of a sequence of quantities**. Most signals in life are analog signals. A familiar example of an Analog Signal would be how the temperature throughout the day is continuously changing and could not suddenly change instantaneously from 0°C to 10°C. However, Digital Signals can instantaneously change in value. This change is expressed in numbers as 1 and 0 (the basis of binary code). Their differences can more easily be seen when compared when graphed as below.



Note that the Analog signals are curved waves and the Digital signals are "Square Waves".

In practical applications, we often use binary as the digital signal that is a series of 0's and 1's. Since a binary signal only has two values (0 or 1) it has great stability and reliability. Lastly, both analog and digital signals can be converted into the other.

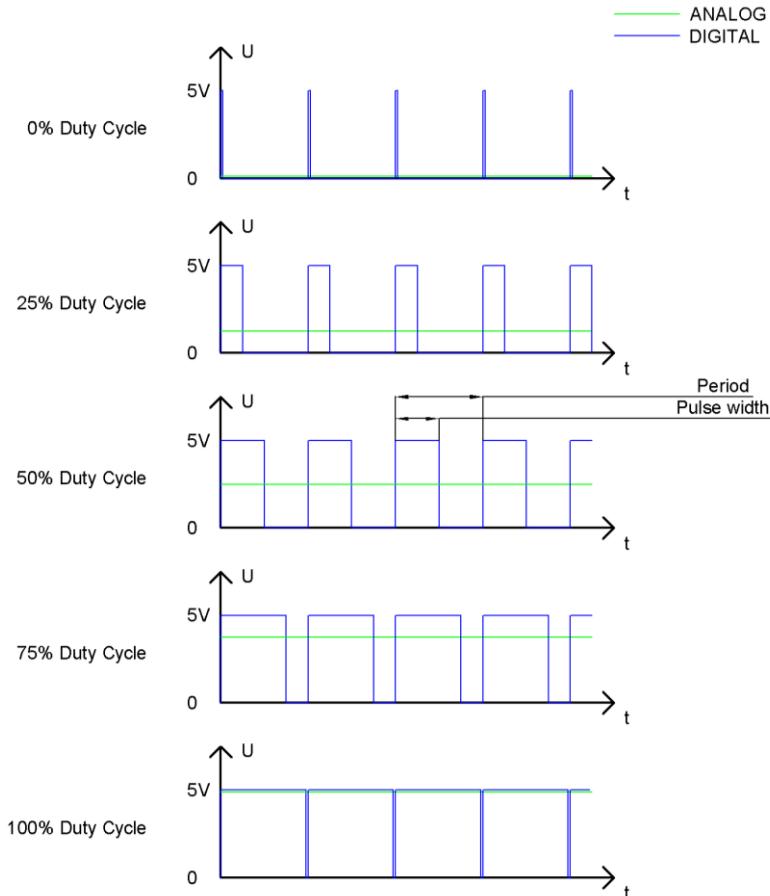
### PWM

PWM, Pulse-Width Modulation, is a very effective method for using digital signals to control analog circuits. Digital processors cannot directly output analog signals. PWM technology makes it very convenient to achieve this conversion (translation of digital to analog signals).

PWM technology uses digital pins to send certain frequencies of square waves, that is, the output of high levels and low levels, which alternately last for a while. The total time for each set of high levels and low levels is



generally fixed, which is called the period (Note: the reciprocal of the period is frequency). The time of high level outputs are generally called “pulse width”, and the duty cycle is the percentage of the ratio of pulse duration, or pulse width (PW) to the total period (T) of the waveform. The longer the output of high levels last, the longer the duty cycle and the higher the corresponding voltage in the analog signal will be. The following figures show how the analog signal voltages vary between 0V-5V (high level is 5V) corresponding to the pulse width 0%-100%:



The longer the PWM duty cycle is, the higher the output power will be. Now that we understand this relationship, we can use PWM to control the brightness of an LED or the speed of DC motor and so on.

It is evident, from the above, that PWM is not actually analog but the effective value of voltage is equivalent to the corresponding analog value. Therefore, by using PWM, we can control the output power of to an LED and control other devices and modules to achieve multiple effects and actions.

In RPi, GPIO18 pin has the ability to output to hardware via PWM with a 10-bit accuracy. This means that 100% of the pulse width can be divided into  $2^{10} = 1024$  equal parts.

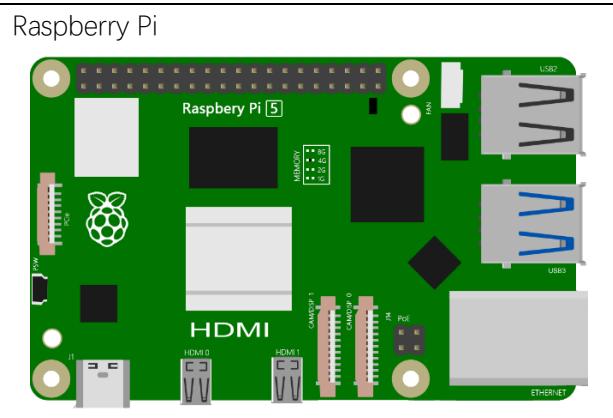
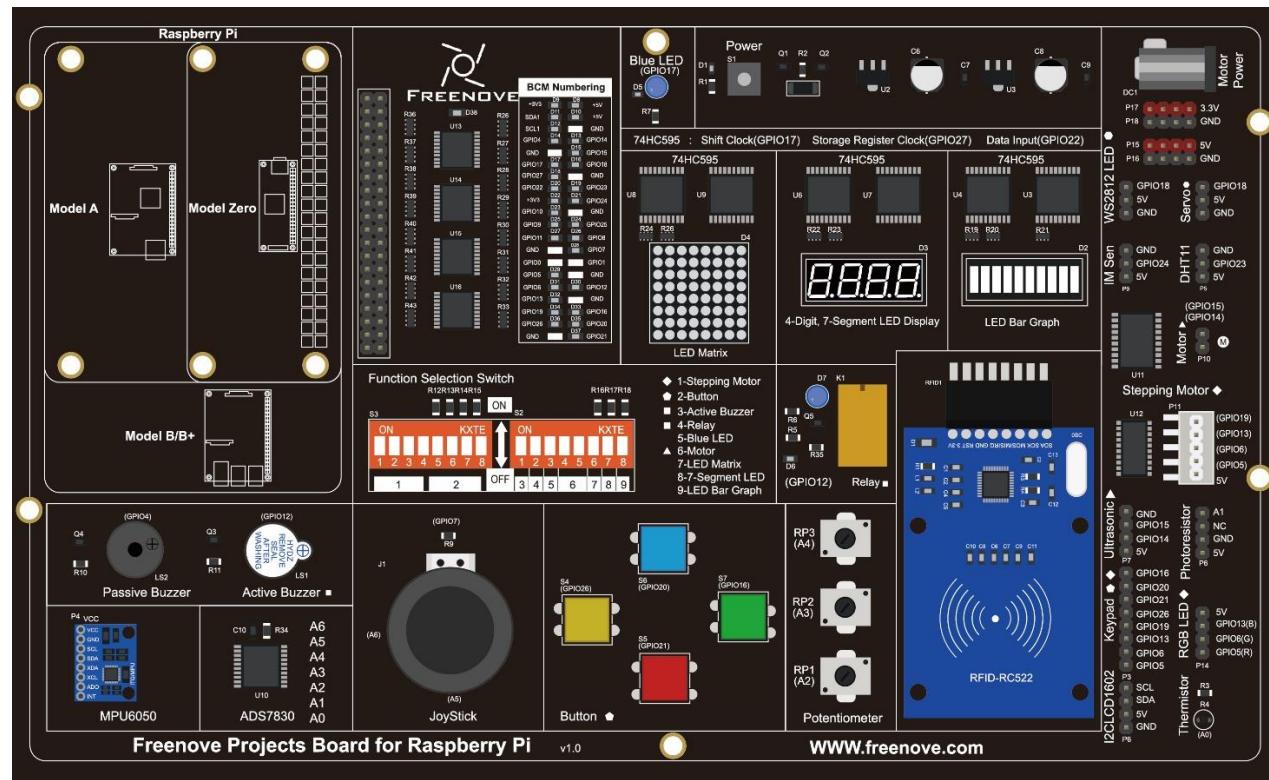
The wiringPi library of C provides both a hardware PWM and a software PWM method, while the wiringPi library of Python does not provide a hardware PWM method. There is only a software PWM option for Python.

The hardware PWM only needs to be configured, does not require CPU resources and is more precise in time control. The software PWM requires the CPU to work continuously by using code to output high level and low level. This part of the code is carried out by multi-threading, and the accuracy is relatively not high enough.

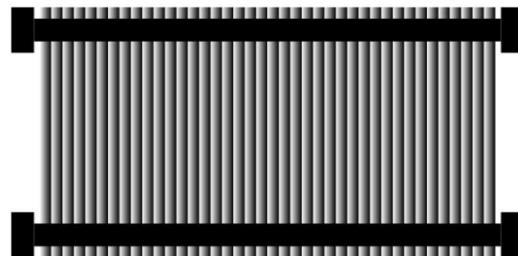
In order to keep the results running consistently, we will use PWM.

## Component List

Freenove Projects Board for Raspberry Pi

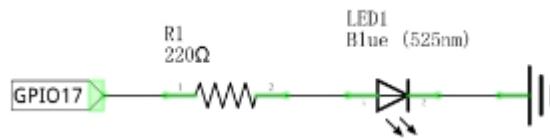


GPIO Ribbon Cable

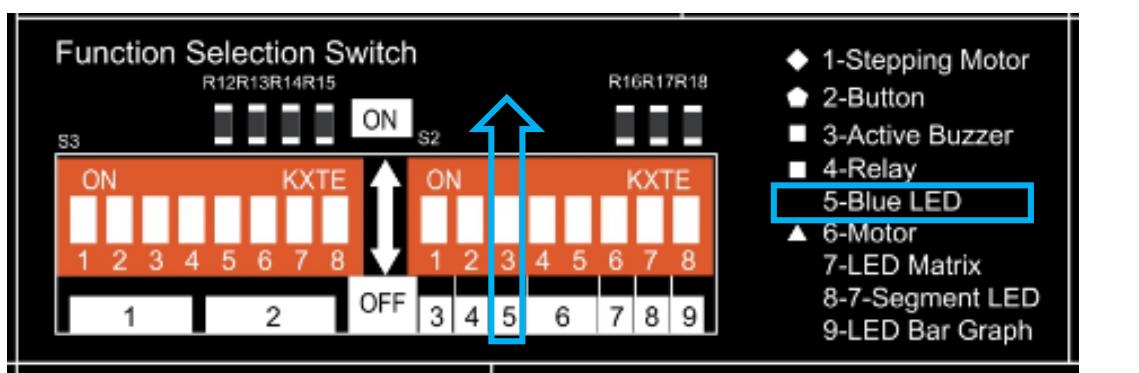
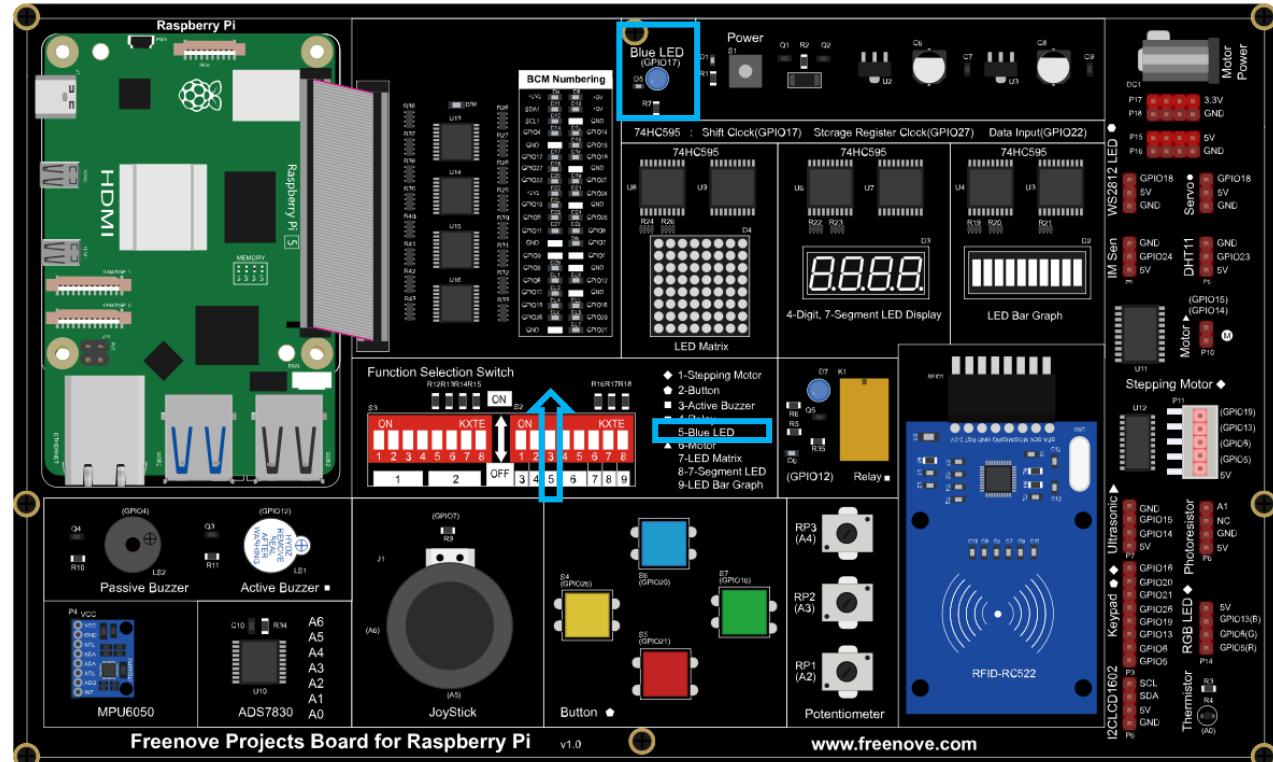


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this chapter, we will learn how to make the LED to present a breathing effect.

### Sketch\_04\_BreathingLED

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_04_BreathingLED
```

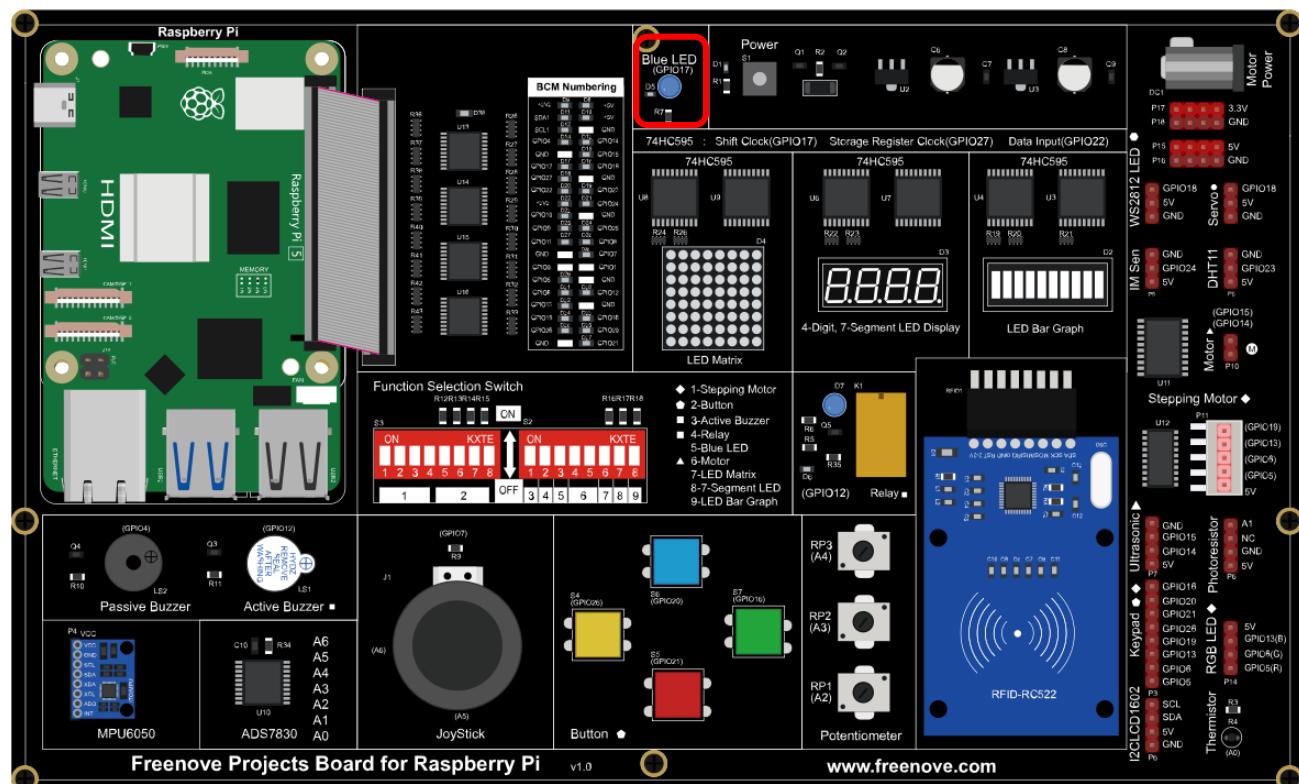
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_04_BreathingLED
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_04_BreathingLED $
```

You can enter the command to run the code.

```
jbang BreathingLED.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_04_BreathingLED
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_04_BreathingLED $ jbang BreathingLED.java
```

When the code is running, you can see the LED lights up from dim to bright and then from bright to dim, and the process repeats.



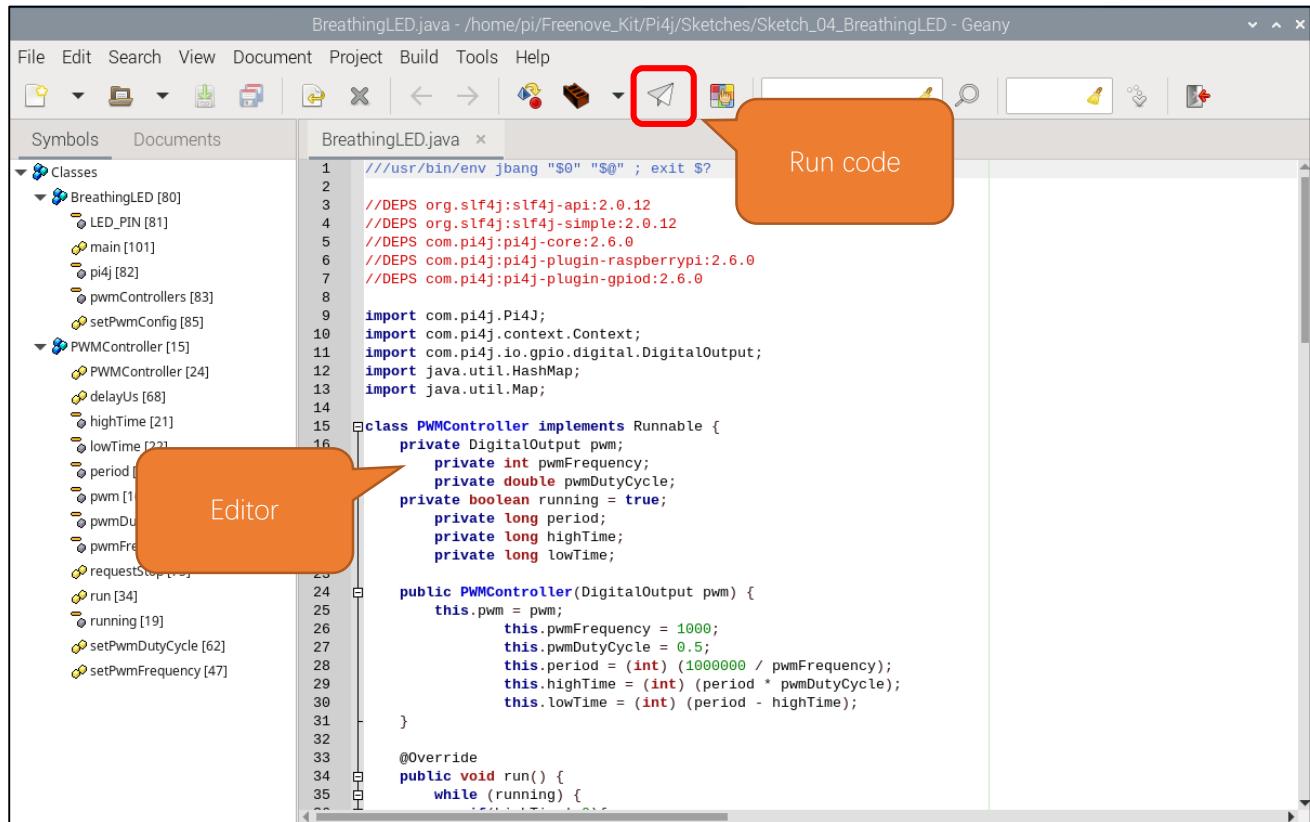
Press Ctrl-C to exit the code.

```
[main] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully initialized.
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime.
...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_04_BreathingLED $
```

You can open the code with Geany to view and edit it.

### geany BreathingLED.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.gpio.digital.DigitalOutput;
12 import java.util.HashMap;
13 import java.util.Map;
14
15 class PWMController implements Runnable {
16     private DigitalOutput pwm;
17     private int pwmFrequency;

```

```
18  private double pwmDutyCycle;
19  private boolean running = true;
20  private long period;
21  private long highTime;
22  private long lowTime;
23
24  public PWMController(DigitalOutput pwm) {
25      this.pwm = pwm;
26      this.pwmFrequency = 1000;
27      this.pwmDutyCycle = 0.5;
28      this.period = (int) (1000000 / pwmFrequency);
29      this.highTime = (int) (period * pwmDutyCycle);
30      this.lowTime = (int) (period - highTime);
31  }
32
33  @Override
34  public void run() {
35      while (running) {
36          if(highTime!=0) {
37              pwm.high();
38              delayUs(highTime);
39          }
40          if(lowTime!=0) {
41              pwm.low();
42              delayUs(lowTime);
43          }
44      }
45  }
46
47  public void setPwmFrequency(int frequency) {
48      if(frequency!=0) {
49          this.pwmFrequency = frequency;
50          this.period = (int) (1000000 / pwmFrequency);
51          this.highTime = (int) (period * pwmDutyCycle);
52          this.lowTime = (int) (period - highTime);
53      }
54      else{
55          this.pwmFrequency = 0;
56          this.period = (int) (1000);
57          this.highTime = (int) (0);
58          this.lowTime = (int) (period - highTime);
59      }
60  }
```

```
62     public void setPwmDutyCycle(double dutyCycle) {
63         this.pwmDutyCycle = dutyCycle;
64         this.highTime = (int) (period * pwmDutyCycle);
65         this.lowTime = (int) (period - highTime);
66     }
67
68     private void delayUs(long us) {
69         long startTime = System.nanoTime();
70         long endTime = startTime + (us * 1000);
71         while (System.nanoTime() < endTime) {
72         }
73     }
74
75     public void requestStop() {
76         running = false;
77     }
78 }
79
80 public class BreathingLED {
81     private static int LED_PIN = 17;
82     private static final Context pi4j = Pi4J.newAutoContext();
83     private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
84
85     public static void setPwmConfig(int pin) throws Exception {
86         DigitalOutput led = pi4j.dout().create(pin);
87         PWMController = new PWMController(led);
88         Thread pwmThread = new Thread(pwmController, "PWM LED Controller " + pin);
89         pwmControllers.put(pin, pwmController);
90         pwmThread.start();
91         Runtime.getRuntime().addShutdownHook(new Thread(() -> {
92             pwmController.requestStop();
93             try {
94                 pwmThread.join();
95             } catch (InterruptedException e) {
96                 Thread.currentThread().interrupt();
97             }
98         }));
99     }
100
101     public static void main(String[] args) throws Exception {
102         setPwmConfig(LED_PIN);
103         PWMController BreathingLed = pwmControllers.get(LED_PIN);
104         try {
105             while (true) {
```

```

106         double dutyCycle = 0.01;
107         while (dutyCycle < 1) {
108             BreathingLed.setPwmDutyCycle(dutyCycle);
109             dutyCycle += 0.01;
110             Thread.sleep(10);
111         }
112         while (dutyCycle > 0) {
113             BreathingLed.setPwmDutyCycle(dutyCycle);
114             dutyCycle -= 0.01;
115             Thread.sleep(10);
116         }
117     }
118 }
119 finally {
120     for (PWMController controller : pwmControllers.values()) {
121         controller.requestStop();
122     }
123     pi4j.shutdown();
124 }
125 }
126 }
```

Use JBang to run the script and automatically process the declared dependencies.

```

//usr/bin/env jbang "$0" "$@" ; exit $?

//DEPS org.slf4j:slf4j-api:2.0.12
//DEPS org.slf4j:slf4j-simple:2.0.12
//DEPS com.pi4j:pi4j-core:2.6.0
//DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
//DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
```

Import Pi4J library, context management, digital output interface, HashMap class, and Map interface.

```

import com.pi4j.Pi4J;
import com.pi4j.context.Context;
import com.pi4j.io.gpio.digital.DigitalOutput;
import java.util.HashMap;
import java.util.Map;
```



Pi4j only has 4 hardware PWM pins, and the use of these pins is greatly limited, so we use software PWM to control the LED. Although software PWM is not as precise as hardware PWM, it can be applied to any GPIO. To implement software PWM, we have written a PWMController class to control the GPIO output of PWM. Since PWMController implements the Runnable interface, it can be used to create a Thread object, passing an instance of PWMController as the target to the Thread constructor, and then starting this thread. In this way, the run method of PWMController will be executed in a new thread, allowing it to perform PWM control tasks concurrently.

```
class PWMController implements Runnable {
    .....
}
```

Define variables to configure PWM's parameters.

```
private DigitalOutput pwm;
private int pwmFrequency;
private double pwmDutyCycle;
private boolean running = true;
private long period;
private long highTime;
private long lowTime;
```

Constructor, to initialize various parameters of the PWM controller.

```
public PWMController(DigitalOutput pwm) {
    this.pwm = pwm;
    this.pwmFrequency = 1000;
    this.pwmDutyCycle = 0.5;
    this.period = (int) (1000000 / pwmFrequency);
    this.highTime = (int) (period * pwmDutyCycle);
    this.lowTime = (int) (period - highTime);
}
```

This is a simple delay method in microsecond.

```
private void delayUs(long us) {
    long startTime = System.nanoTime();
    long endTime = startTime + (us * 1000);
    while (System.nanoTime() < endTime) {
    }
}
```

The functions to set PWM frequency.

```
public void setPwmFrequency(int frequency) {
    if(frequency!=0) {
        this.pwmFrequency = frequency;
        this.period = (int) (1000000 / pwmFrequency);
        this.highTime = (int) (period * pwmDutyCycle);
        this.lowTime = (int) (period - highTime);
    }
    else{
        this.pwmFrequency = 0;
        this.period = (int) (1000);
        this.highTime = (int) (0);
        this.lowTime = (int) (period - highTime);
    }
}
```

The functions to set PWM duty cycle.

```
public void setPwmDutyCycle(double dutyCycle) {
    this.pwmDutyCycle = dutyCycle;
    this.highTime = (int) (period * pwmDutyCycle);
    this.lowTime = (int) (period - highTime);
}
```

@Override means that the run method overrides the method in the parent class or implements the interface. This method allows the pin to output PWM signals.

```
@Override
public void run() {
    while (running) {
        if(highTime!=0) {
            pwm.high();
            delayUs(highTime);
        }
        if(lowTime!=0) {
            pwm.low();
            delayUs(lowTime);
        }
    }
}
```

Request to stop the PWM controller. The PWMController class is used in the thread. When running is false, exit the thread.

```
public void requestStop() {
    running = false;
}
```

Define the pins that control PWM and create an integer Map variable `pwmControllers` to store the mapping of `PWMController` objects.

```
private static int LED_PIN = 17;
private static final Context pi4j = Pi4J.newAutoContext();
private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
```

The PWM configuration function only needs to fill in the GPIO number in the parameter. The code will automatically apply for a `PWMController` object and create a corresponding thread to run it. At the same time, the `PWMController` is stored in `pwmControllers` and then the thread is started.

```
public static void setPwmConfig(int pin) throws Exception {
    DigitalOutput led = pi4j.dout().create(pin);
    PWMController pwmController = new PWMController(led);
    Thread pwmThread = new Thread(pwmController, "PWM LED Controller " + pin);
    pwmControllers.put(pin, pwmController);
    pwmThread.start();
    .....
}
```

Add JVM shutdown hook to ensure PWM controller is stopped on JVM shutdown.

```
Runtime.getRuntime().addShutdownHook(new Thread(() -> {
    pwmController.requestStop();
    try {
        pwmThread.join();
    } catch (InterruptedException e) {
        Thread.currentThread().interrupt();
    }
}));
```

The main program, which is used to test the effect of making the LED breathe.

```
public static void main(String[] args) throws Exception {
    .....
}
```

Configure PWM and associate it with pin.

```
setPwmConfig(LED_PIN);
```

Obtain PWM controller corresponding to the pin.

```
PWMController BreathingLed = pwmControllers.get(LED_PIN);
```

The duty cycle value is changed every 10 milliseconds, so that the LED cycles from dark to bright and then from bright to dark.

```
try {
    while (true) {
        double dutyCycle = 0.01;
        while (dutyCycle < 1) {
            BreathingLed.setPwmDutyCycle(dutyCycle);
            dutyCycle += 0.01;
            Thread.sleep(10);
        }
        while (dutyCycle > 0) {
            BreathingLed.setPwmDutyCycle(dutyCycle);
            dutyCycle -= 0.01;
            Thread.sleep(10);
        }
    }
}
```

When exiting the main loop, first close all PWM controller threads and then close the pi4j context.

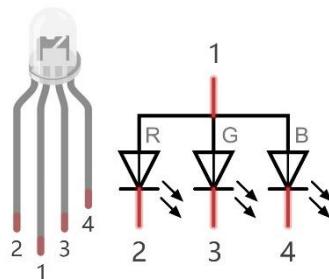
```
finally {
    for (PWMController controller : pwmControllers.values()) {
        controller.requestStop();
    }
    pi4j.shutdown();
}
```

# Chapter 5 RGB LED

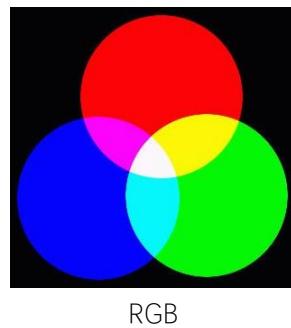
In this chapter, we will learn how to control an RGB LED.

An RGB LED has 3 LEDs integrated into one LED component. It can respectively emit Red, Green and Blue light.

In order to do this, it requires 4 pins (this is also how you identify it). The long pin (1) is the common which is the Anode (+) or positive lead, the other 3 are the Cathodes (-) or negative leads. A rendering of an RGB LED and its electronic symbol are shown below. We can make RGB LED emit various colors of light and brightness by controlling the 3 Cathodes (2, 3 & 4) of the RGB LED



Red, Green, and Blue light are called 3 Primary Colors when discussing light (Note: for pigments such as paints, the 3 Primary Colors are Red, Blue and Yellow). When you combine these three Primary Colors of light with varied brightness, they can produce almost any color of visible light. Computer screens, single pixels of cell phone screens, neon lamps, etc. can all produce millions of colors due to phenomenon.



If we use a three 8 bit PWM to control the RGB LED, in theory, we can create  $2^8 * 2^8 * 2^8 = 16777216$  (16 million) colors through different combinations of RGB light brightness.

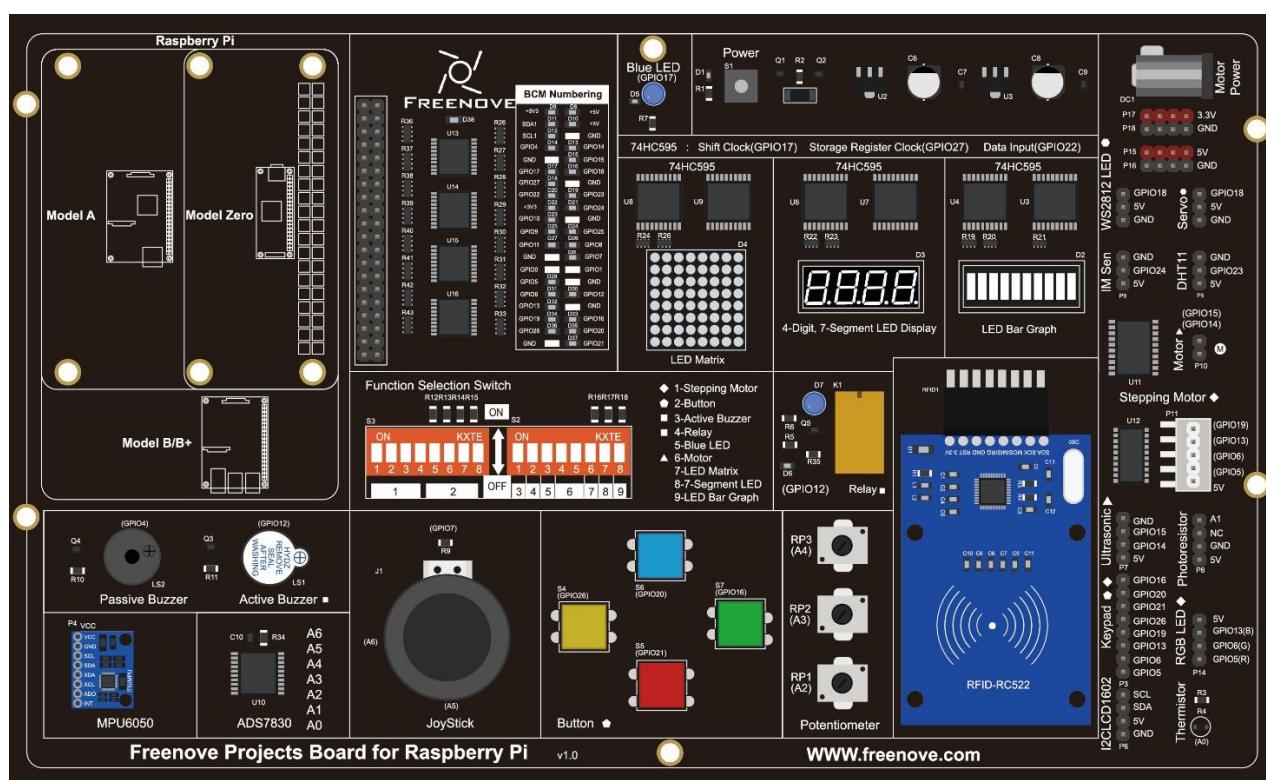
Next, we will use RGB LED to make a multicolored LED.

## Project 5.1 RainbowLED

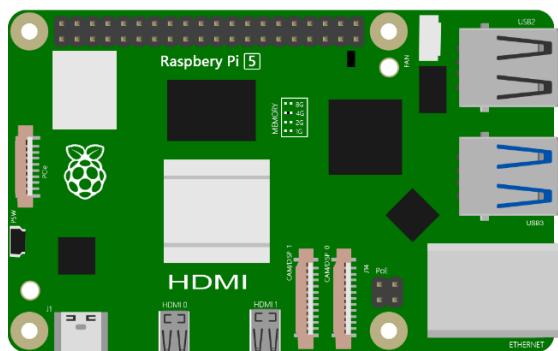
In this project, we will make a multicolored LED, which we can program the RGB LED to automatically change colors.

### Component List

Freenove Projects Board for Raspberry Pi

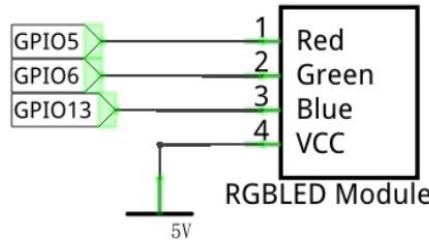


Raspberry Pi

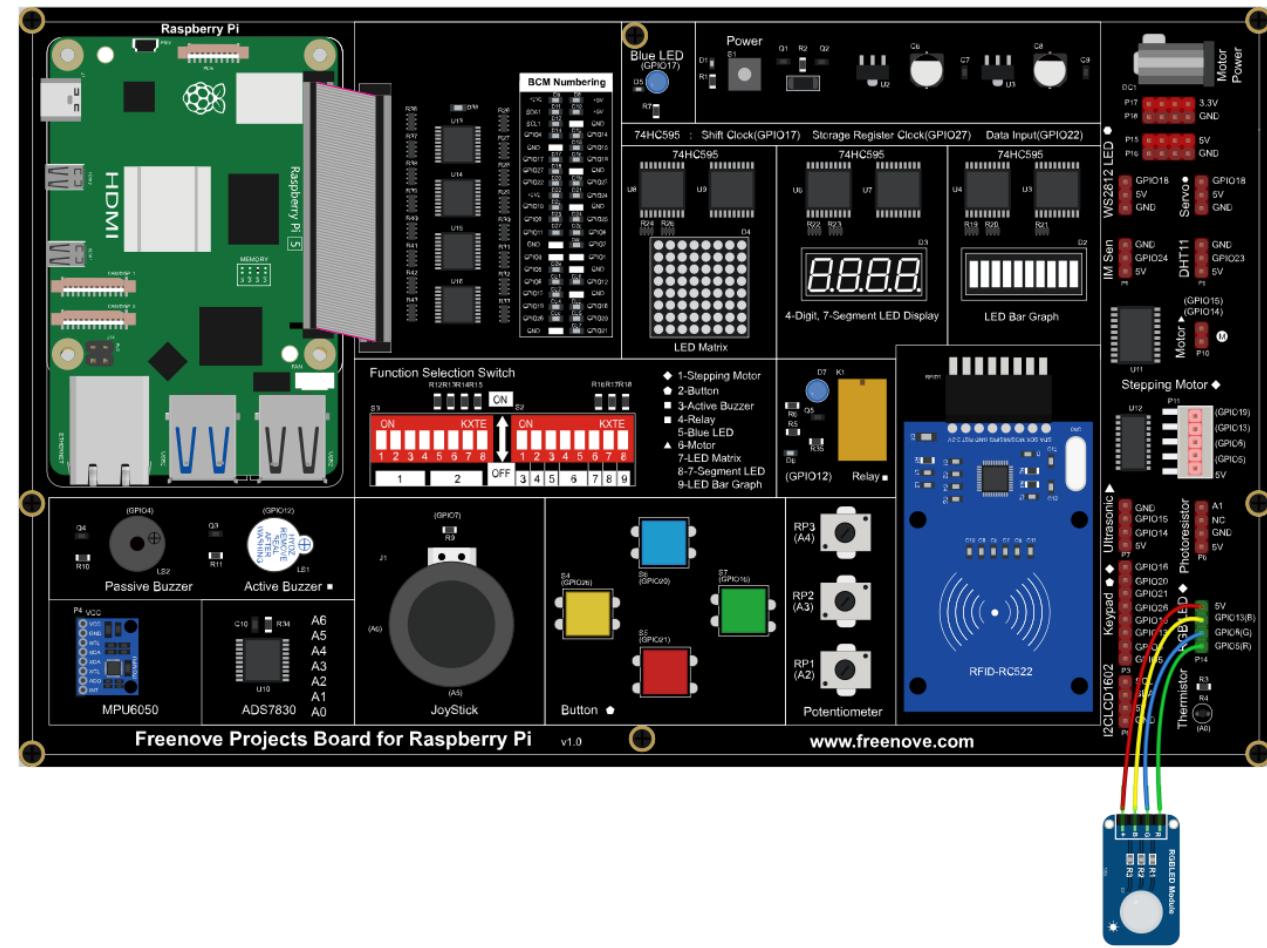


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this chapter, we will control the RGB LED with 3 PWMs.

### Sketch\_05\_RainbowLED

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_05_RainbowLED
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_05_RainbowLED
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_05_RainbowLED $
```

Enter the command to run the code.

```
jbang RainbowLED.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_05_RainbowLED
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_05_RainbowLED $ jbang RainbowLED.java
```

When the code is running, the RGB LED randomly emits various colors.



```
[main] INFO com.pi4j.util.Console - R:69 G:68, B:10
[main] INFO com.pi4j.util.Console - R:80 G:33, B:96
[main] INFO com.pi4j.util.Console - R:43 G:33, B:87
[main] INFO com.pi4j.util.Console - R:28 G:17, B:98
[main] INFO com.pi4j.util.Console - R:16 G:33, B:55
[main] INFO com.pi4j.util.Console - R:81 G:88, B:53
[main] INFO com.pi4j.util.Console - R:45 G:98, B:82
[main] INFO com.pi4j.util.Console - R:52 G:73, B:45
```

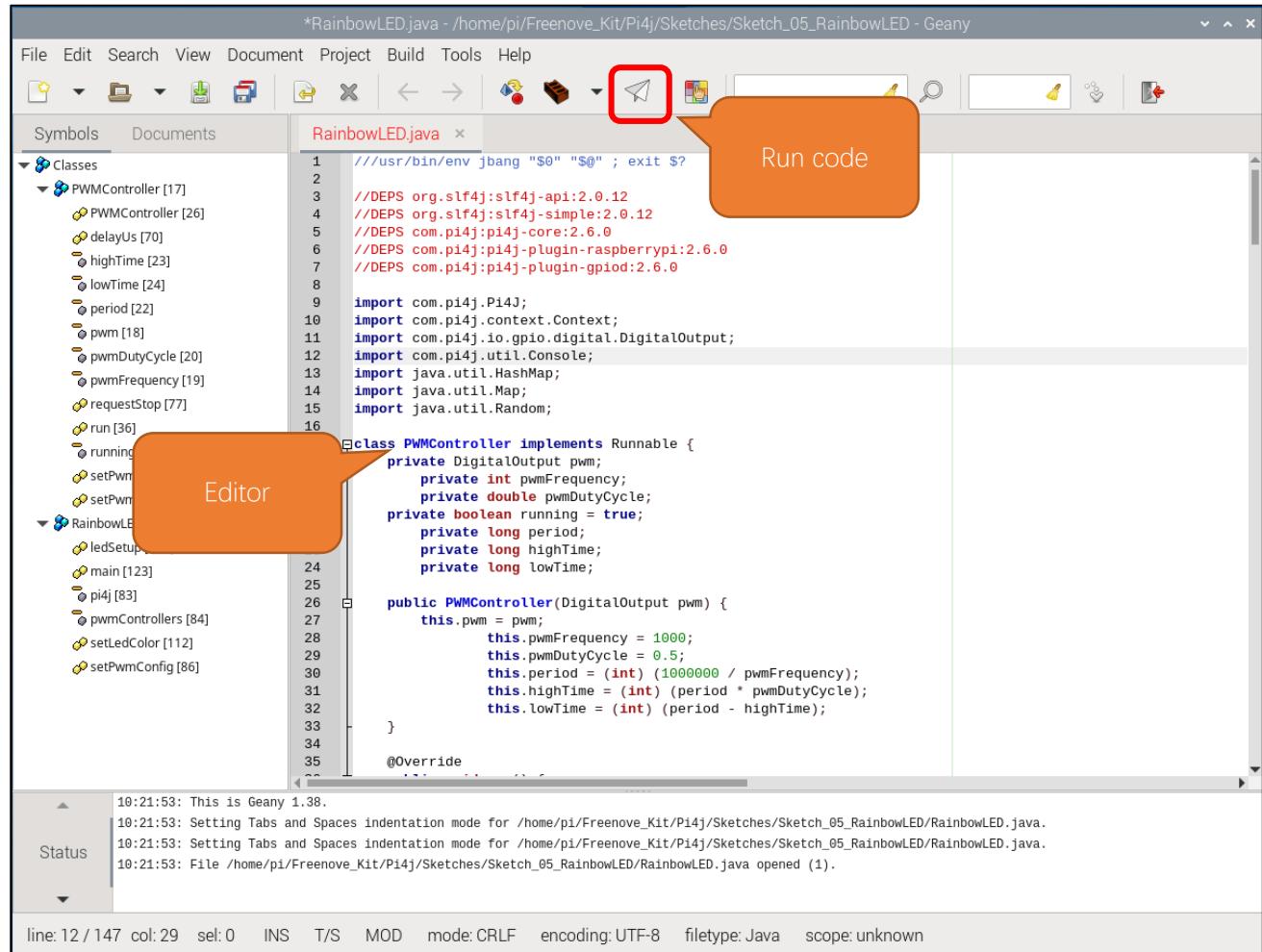
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.util.Console - R:60 G:6, B:66
[main] INFO com.pi4j.util.Console - R:69 G:87, B:89
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime
...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_05_RainbowLED $
```

You can open the code with Geany to view and edit it, with the following command.

**geany RainbowLED.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.gpio.digital.DigitalOutput;
12 import com.pi4j.util.Console;
13 import java.util.HashMap;
```

```
14 import java.util.Map;
15 import java.util.Random;
16
17 class PWMController implements Runnable {
...
    .....
80 }
81
82 public class RainbowLED {
83     private static final Context pi4j = Pi4J.newAutoContext();
84     private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
85
86     public static void setPwmConfig(int pin) throws Exception {
...
    .....
100 }
101
102     public static void ledSetup(int[] pins) {
103         for (int pin : pins) {
104             try {
105                 setPwmConfig(pin);
106             } catch (Exception e) {
107                 e.printStackTrace();
108             }
109         }
110     }
111
112     public static void setLedColor(int[] pins, int r, int g, int b) {
113         if (pins.length >= 3) {
114             PWMController red = pwmControllers.get(pins[0]);
115             PWMController green = pwmControllers.get(pins[1]);
116             PWMController blue = pwmControllers.get(pins[2]);
117             if (red != null) red.setPwmDutyCycle((double) r / 100.0);
118             if (green != null) green.setPwmDutyCycle((double) g / 100.0);
119             if (blue != null) blue.setPwmDutyCycle((double) b / 100.0);
120         }
121     }
122
123     public static void main(String[] args) throws Exception {
124         final var console = new Console();
125         int[] LED_PINS = {13, 6, 5};
126         Random = new Random();
127
128         try {
129             ledSetup(LED_PINS);
130             while (true) {
```

```

131         int red = random.nextInt(101);
132         int green = random.nextInt(101);
133         int blue = random.nextInt(101);
134         console.println("R:%d  G:%d, B:%d", red, green, blue);
134         setLedColor(LED_PINS, red, green, blue);
135         Thread.sleep(500);
136     }
137 }
138 finally {
139     for (PWMController controller : pwmControllers.values()) {
140         controller.requestStop();
141     }
142     pi4j.shutdown();
143 }
144 }
145 }
```

Import Pi4j library, context management, digital output interface, HashMap class and Map interface, and random function library.

```

import com.pi4j.Pi4J;
import com.pi4j.context.Context;
import com.pi4j.io.gpio.digital.DigitalOutput;
import com.pi4j.util.Console;
import java.util.HashMap;
import java.util.Map;
import java.util.Random;
```

Initialize the pins corresponding to the RGB lights and print a stack trace if an exception occurs.

```

public static void ledSetup(int[] pins) {
    for (int pin : pins) {
        try {
            setPwmConfig(pin);
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```

Configure the RGB colored lights and adjust the brightness of the LED by adjusting the duty cycle of PWM.

```
public static void setLedColor(int[] pins, int r, int g, int b) {
    if (pins.length >= 3) {
        PWMController red = pwmControllers.get(pins[0]);
        PWMController green = pwmControllers.get(pins[1]);
        PWMController blue = pwmControllers.get(pins[2]);
        if (red != null) red.setPwmDutyCycle((double) r / 100.0);
        if (green != null) green.setPwmDutyCycle((double) g / 100.0);
        if (blue != null) blue.setPwmDutyCycle((double) b / 100.0);
    }
}
```

Create a console instance, define an array of GPIO pins for LED connections, and create a random number generator instance.

```
final var console = new Console();
int[] LED_PINS = {13, 6, 5};
Random = new Random();
```

Initialize the array of GPIO pins connected to the LEDs, generate 3 new random numbers every 500 milliseconds as brightness values for the RGB lights, and print prompt messages on the console.

```
try {
    ledSetup(LED_PINS);
    while (true) {
        int red = random.nextInt(101);
        int green = random.nextInt(101);
        int blue = random.nextInt(101);
        console.println("R:%d G:%d, B:%d", red, green, blue);
        setLedColor(LED_PINS, red, green, blue);
        Thread.sleep(500);
    }
}
```

At the end of the program, stop all PWM controllers and close the Pi4J context.

```
finally {
    for (PWMController controller : pwmControllers.values()) {
        controller.requestStop();
    }
    pi4j.shutdown();
}
```

# Chapter 6 Buzzer

In this chapter, we will learn about buzzers and the sounds they make. And in our next project, we will use an active buzzer to make a doorbell and a passive buzzer to make an alarm.

## Project 6.1 Doorbell

We will make a doorbell with this functionality: when the Push Button Switch is pressed the buzzer sounds and when the button is released, the buzzer stops. This is a momentary switch function.

### Component knowledge

#### Buzzer

A buzzer is an audio component. They are widely used in electronic devices such as calculators, electronic alarm clocks, automobile fault indicators, etc. There are both active and passive types of buzzers. Active buzzers have oscillator inside, these will sound as long as power is supplied. Passive buzzers require an external oscillator signal (generally using PWM with different frequencies) to make a sound.



Active buzzers are easier to use. Generally, they only make a specific sound frequency. Passive buzzers require an external circuit to make sounds, but passive buzzers can be controlled to make sounds of various frequencies. The resonant frequency of the passive buzzer in this Kit is 2kHz, which means the passive buzzer is the loudest when its resonant frequency is 2kHz.

#### How to identify active and passive buzzer?

1. As a rule, there is a label on an active buzzer covering the hole where sound is emitted, but there are exceptions to this rule.
2. Active buzzers are more complex than passive buzzers in their manufacture. There are many circuits and crystal oscillator elements inside active buzzers; all of this is usually protected with a waterproof coating (and a housing) exposing only its pins from the underside. On the other hand, passive buzzers do not have protective coatings on their underside. From the pinholes, view of a passive buzzer, you can see the circuit board, coils, and a permanent magnet (all or any combination of these components depending on the model).



Active buzzer bottom



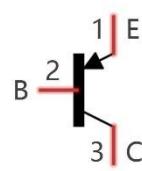
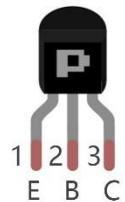
Passive buzzer bottom

### Transistors

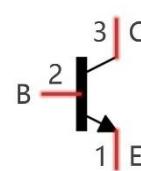
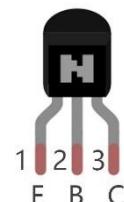
A transistor is required in this project due to the buzzer's current being so great that GPIO of RPi's output capability cannot meet the power requirement necessary for operation. A NPN transistor is needed here to amplify the current.

Transistors, full name: semiconductor transistor, is a semiconductor device that controls current (think of a transistor as an electronic "amplifying or switching device"). Transistors can be used to amplify weak signals, or to work as a switch. Transistors have three electrodes (PINs): base (b), collector (c) and emitter (e). When there is current passing between "be" then "ce" will have a several-fold current increase (transistor magnification), in this configuration the transistor acts as an amplifier. When current produced by "be" exceeds a certain value, "ce" will limit the current output. at this point the transistor is working in its saturation region and acts like a switch. Transistors are available as two types as shown below: PNP and NPN,

PNP transistor



NPN transistor

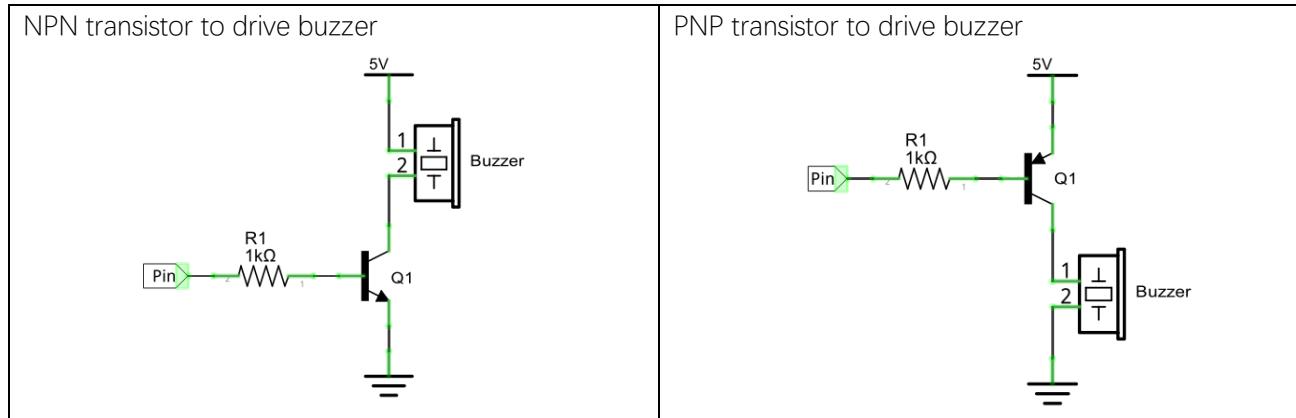


In our kit, the PNP transistor is marked with 8550, and the NPN transistor is marked with 8050.

Thanks to the transistor's characteristics, they are often used as switches in digital circuits. As micro-controllers output current capacity is very weak, we will use a transistor to amplify its current in order to drive components requiring higher current.

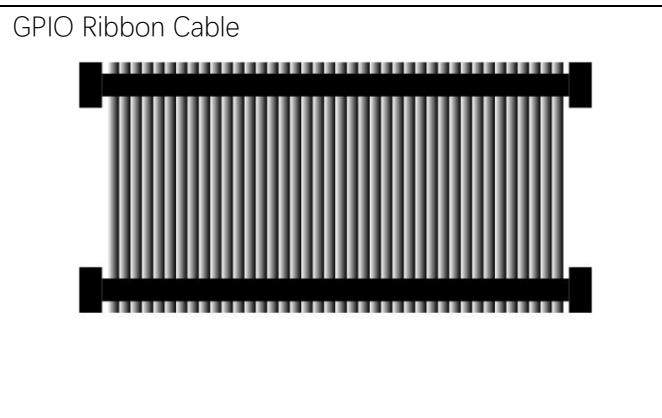
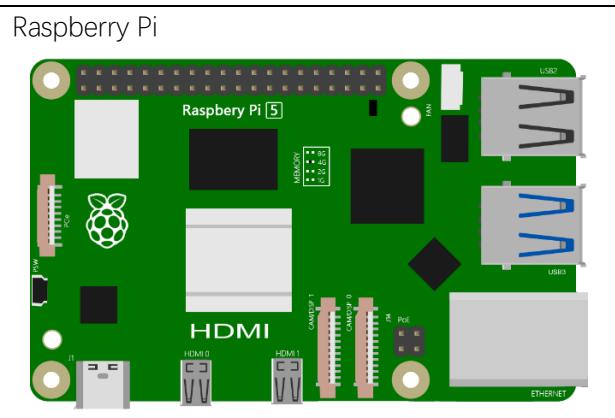
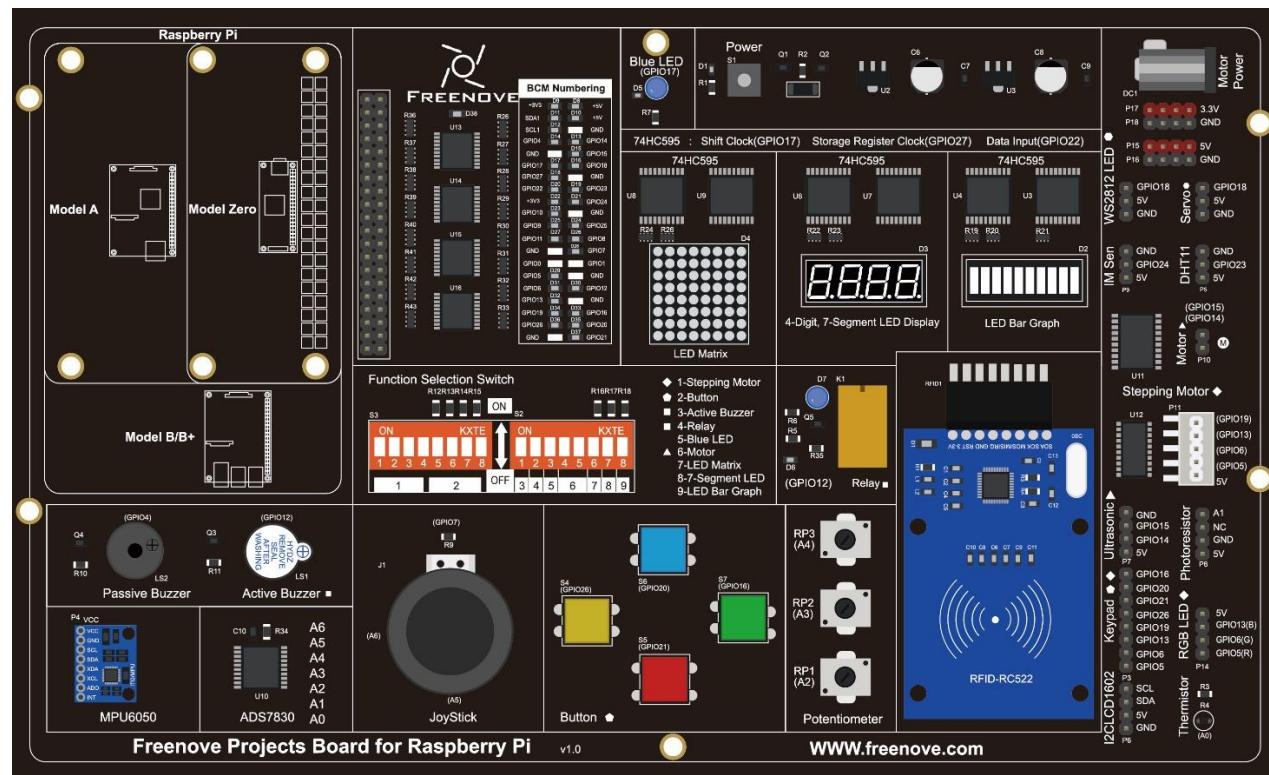
When we use a NPN transistor to drive a buzzer, we often use the following method. If GPIO outputs high level, current will flow through R1 (Resistor 1), the transistor conducts current and the buzzer will make sounds. If GPIO outputs low level, no current will flow through R1, the transistor will not conduct current and buzzer will remain silent (no sounds).

When we use a PNP transistor to drive a buzzer, we often use the following method. If GPIO outputs low level, current will flow through R1. The transistor conducts current and the buzzer will make sounds. If GPIO outputs high level, no current flows through R1, the transistor will not conduct current and buzzer will remain silent (no sounds). Below are the circuit schematics for both a NPN and PNP transistor to power a buzzer.



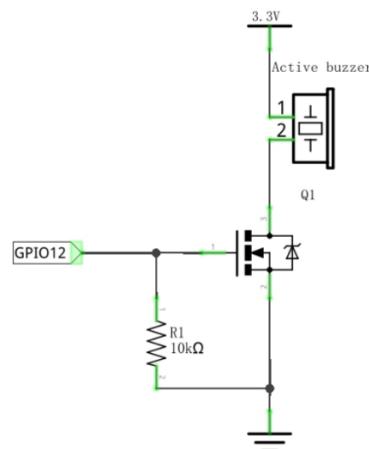
## Component List

Freenove Projects Board for Raspberry Pi

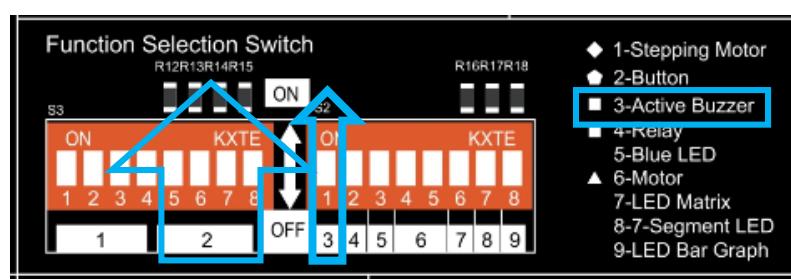
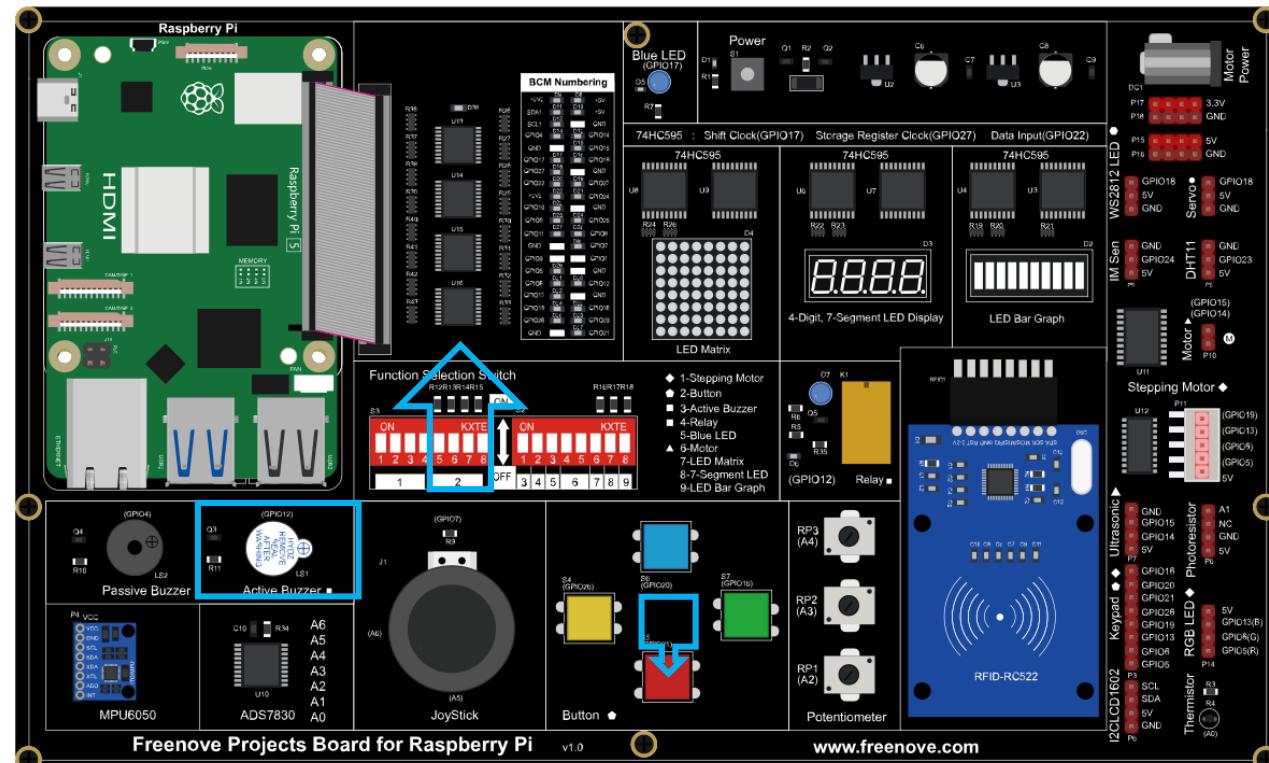


## Circuit

Schematic diagram with RPi GPIO Extension Shield.



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this chapter, we use a button to control the active buzzer. The code is similar to that in Chapter 3.

### Sketch\_06\_1\_Doorbell

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_06_1_Doorbell
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_06_1_Doorbell
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_06_1_Doorbell $
```

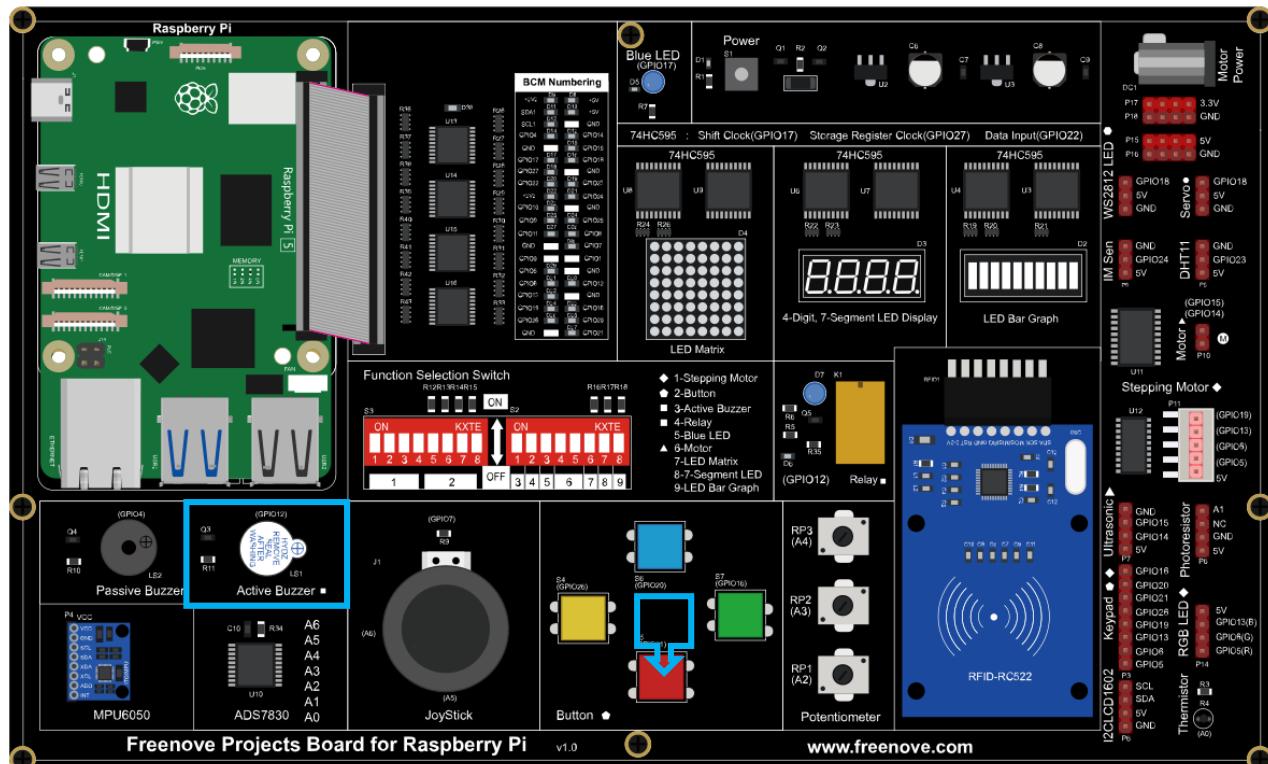
Enter the command to run the code.

```
jbang Doorbell.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_06_1_Doorbell
```

```
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_06_1_Doorbell $ jbang Doorbell.java
```

During the code running, press the button to sound the buzzer and release the button to stop it.



You can see messages printed on the terminal.

```
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - buzzer turned on. >>>
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - buzzer turned off. >>>
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - buzzer turned on. >>>
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - buzzer turned off. >>>
```

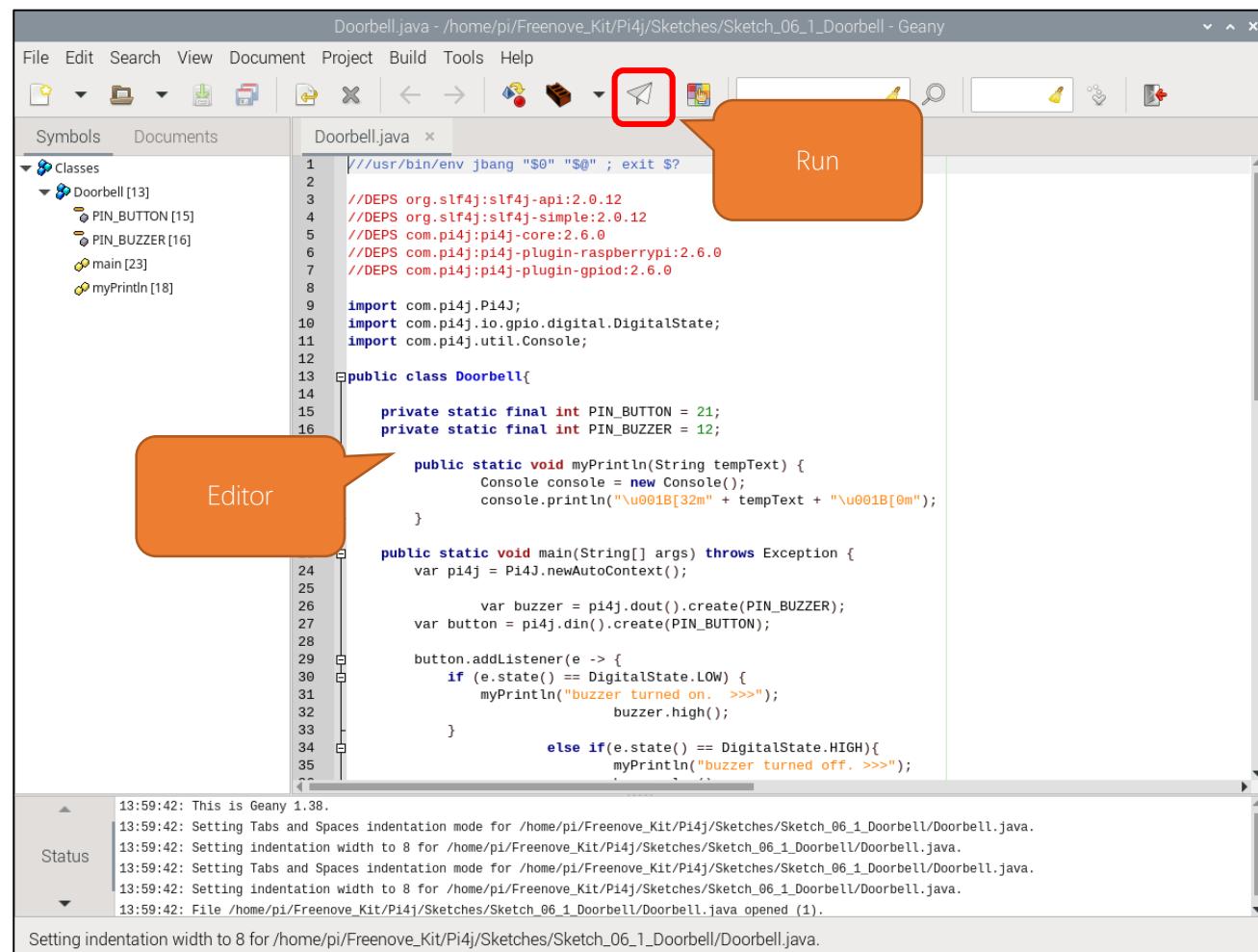
Press Ctrl+C to exit the code.

```
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.plugin.gpio.provider.gpio.digital.GpioDigitalInput - Shutdown input listener for DIN-21
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_06_1_Doorbell $
```

You can open the code with Geany to view and edit it, with the following command.

**geany Doorbell.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.io.gpio.digital.DigitalState;
11 import com.pi4j.util.Console;
12
13 public class Doorbell{

```

```

14
15     private static final int PIN_BUTTON = 21;
16     private static final int PIN_BUZZER = 12;
17
18     public static void myPrintln(String tempText) {
19         Console console = new Console();
20         console.println("\u001B[32m" + tempText + "\u001B[0m");
21     }
22
23     public static void main(String[] args) throws Exception {
24         var pi4j = Pi4J.newAutoContext();
25         var buzzer = pi4j.dout().create(PIN_BUZZER);
26         var button = pi4j.din().create(PIN_BUTTON);
27
28         button.addListener(e -> {
29             if (e.state() == DigitalState.LOW) {
30                 myPrintln("buzzer turned on. >>>");
31                 buzzer.high();
32             }
33             else if(e.state() == DigitalState.HIGH) {
34                 myPrintln("buzzer turned off. >>>");
35                 buzzer.low();
36             }
37         });
38
39         try{
40             while (true) {
41                 Thread.sleep(500);
42             }
43         }
44         finally{
45             pi4j.shutdown();
46         }
47     }
48 }
```

Please note that as the code is similar to that in chapter 3, here we do not explain it again.

In order to make the prompt messages printed by the terminal more conspicuous, we wrote the myprintln function to wrap the console.println function.

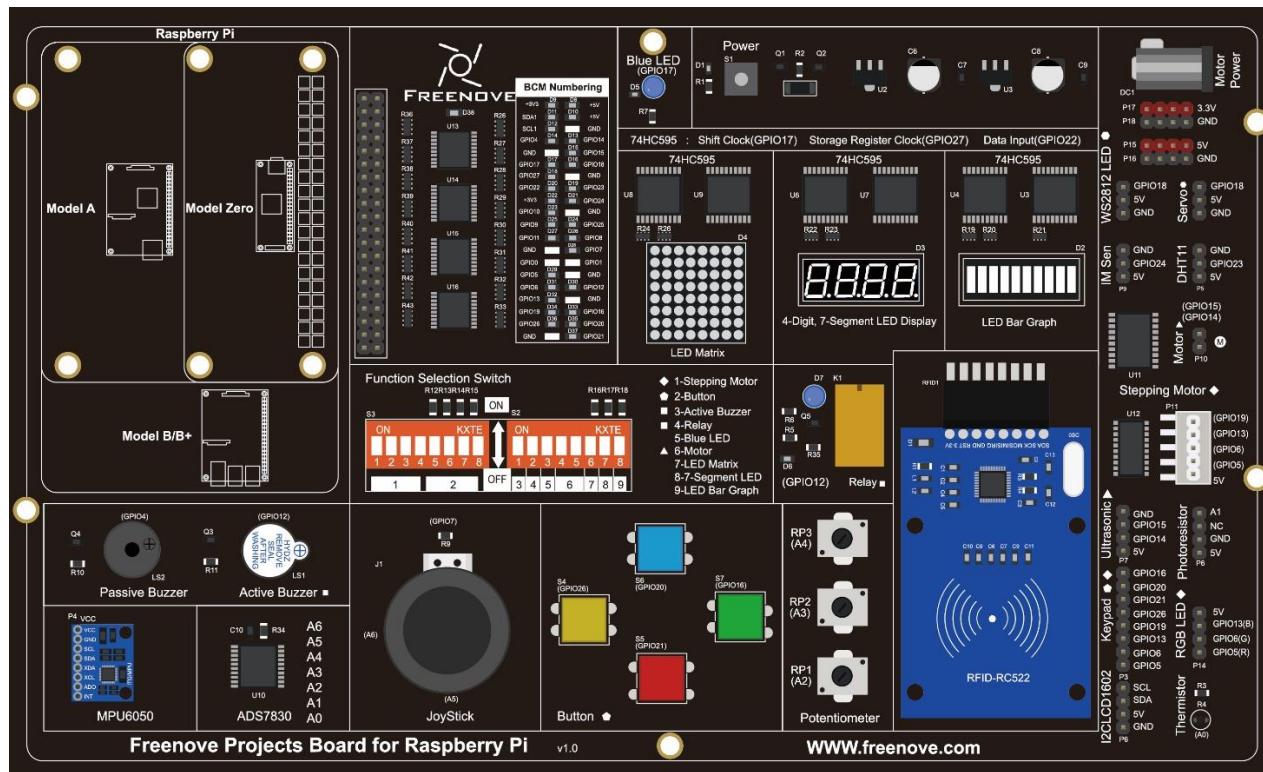
	<pre> public static void myPrintln(String tempText) {     Console console = new Console();     console.println("\u001B[32m" + tempText + "\u001B[0m"); }</pre>
--	--

## Project 6.2 Alertor

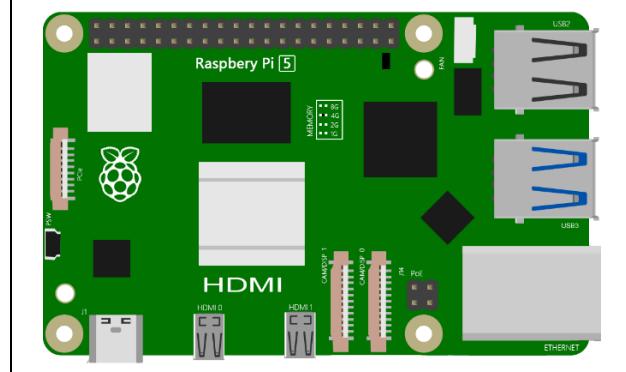
Next, we will use a passive buzzer to make an alarm.

### Component List

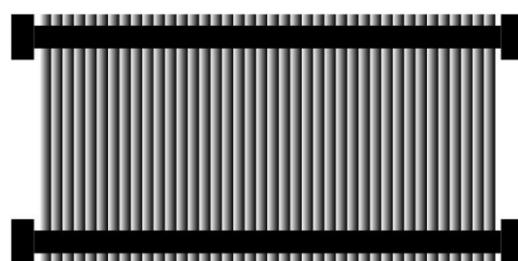
Freenove Projects Board for Raspberry Pi



Raspberry Pi

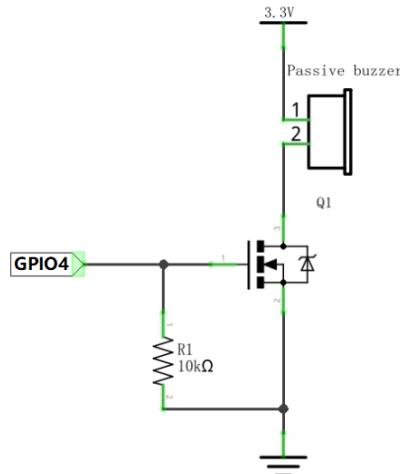


GPIO Ribbon Cable

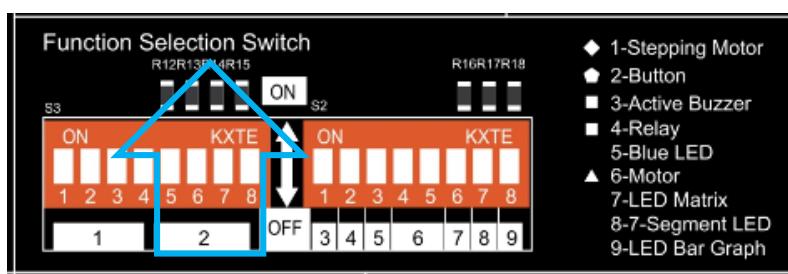
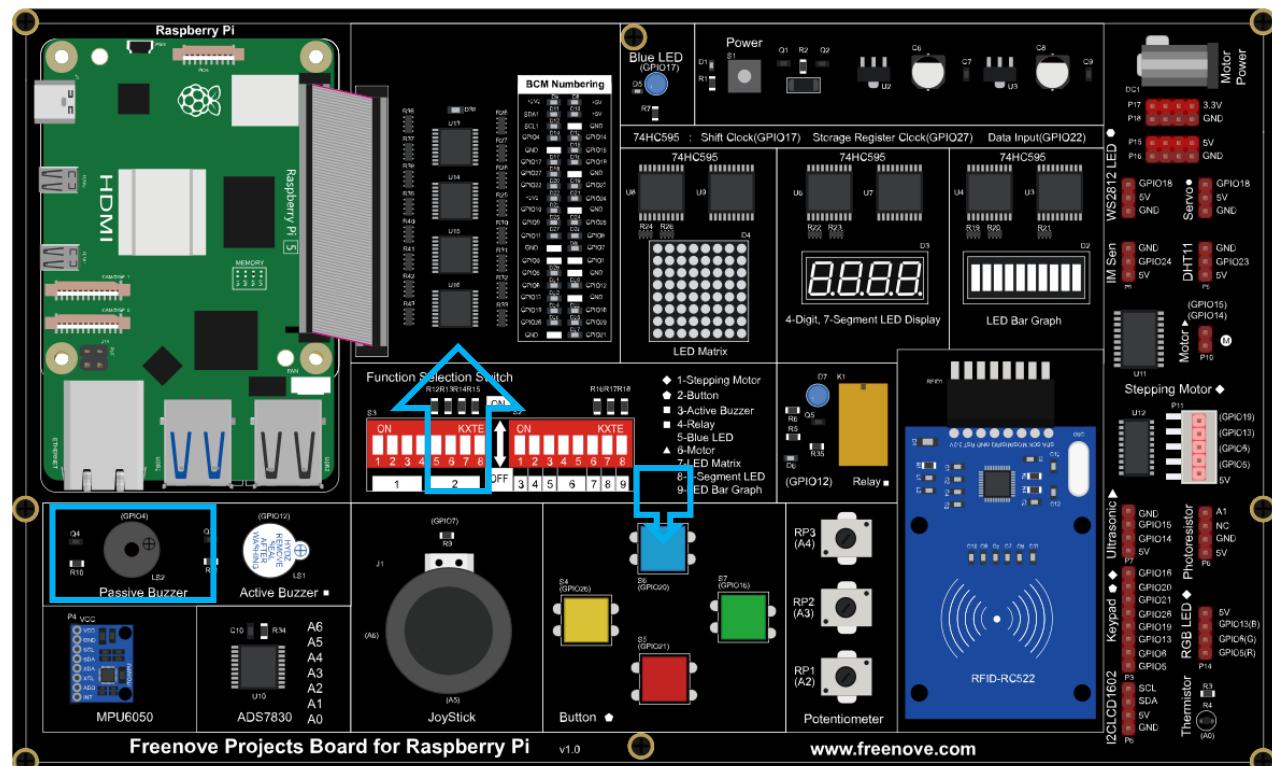


## Circuit

Schematic diagram with RPi GPIO Extension Shield



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this chapter, we use button to control the passive buzzer to make sound.

### Sketch\_06\_2\_Alertor

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_06_2_Alertor
```

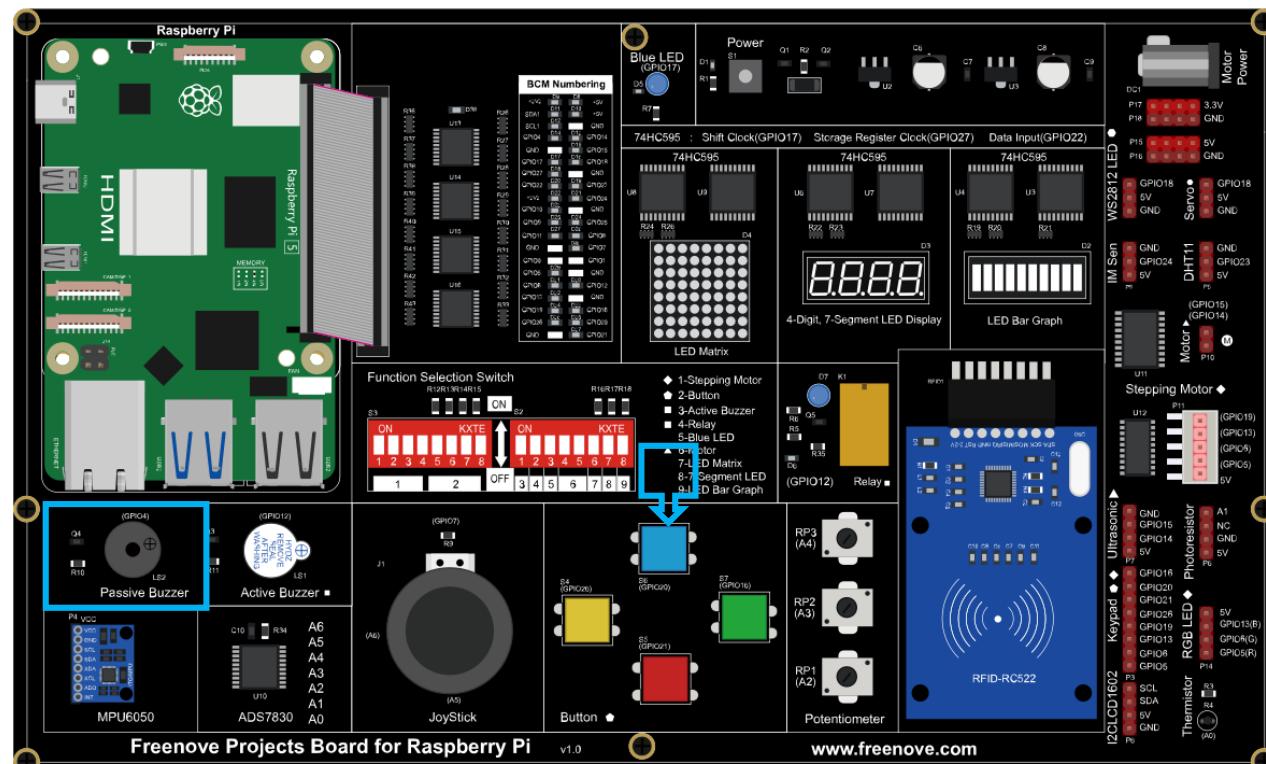
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_06_2_Alertor/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_06_2_Alertor $
```

Enter the command to run the code.

```
jbang Alertor.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_06_2_Alertor/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_06_2_Alertor $ jbang Alertor.java
```

When the code is running, press the button to sound the buzzer and release to stop it.



You can see messages printed on the terminal.

```
[main] INFO com.pi4j.util.Console - buzzer turned off. >>>
[main] INFO com.pi4j.util.Console - buzzer turned on. >>>
[main] INFO com.pi4j.util.Console - buzzer turned on. >>>
[main] INFO com.pi4j.util.Console - buzzer turned off. >>>
[main] INFO com.pi4j.util.Console - buzzer turned off. >>>
[main] INFO com.pi4j.util.Console - buzzer turned off. >>>
```

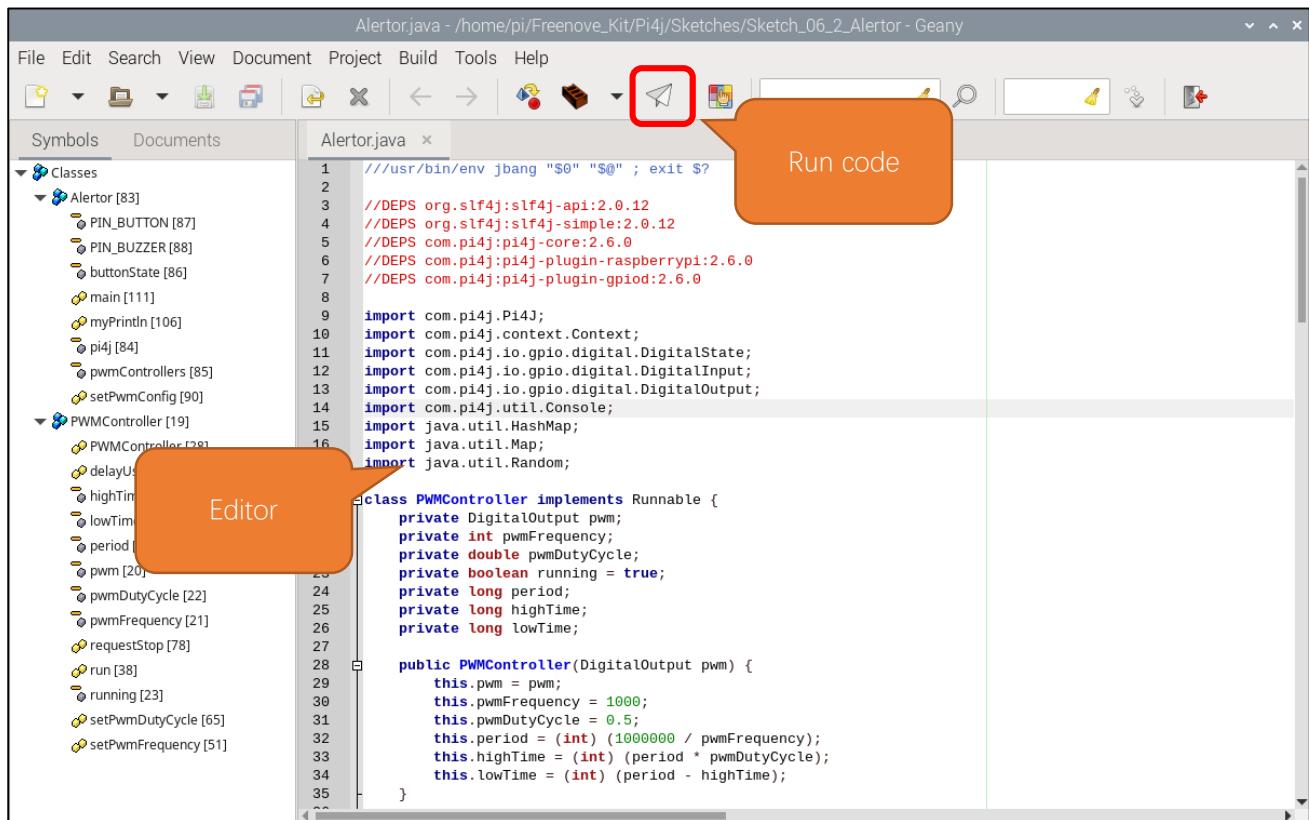
Press **ctrl+C** to exit the code.

```
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.plugin.gpiod.provider.gpio.digital.GpioDDigitalInput - Shutdown input listener for DIN-20
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
```

You can open the code with Geany to view and edit it, with the following command.

**geany Alertor.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.gpio.digital.DigitalState;
12 import com.pi4j.io.gpio.digital.DigitalInput;
13 import com.pi4j.io.gpio.digital.DigitalOutput;
14 import com.pi4j.util.Console;
15 import java.util.HashMap;
16 import java.util.Map;
17 import java.util.Random;

```

```
18
19 class PWMController implements Runnable {
...
81 }
82
83 public class Alertor {
84     private static final Context pi4j = Pi4J.newAutoContext();
85     private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
86     private static volatile int buttonState = 0;
87     private static int PIN_BUTTON = 20;
88     private static int PIN_BUZZER = 4;
89
90     public static void setPwmConfig(int pin) throws Exception {
91         DigitalOutput pwm = pi4j.dout().create(pin);
92         PWMController pwmController = new PWMController(pwm);
93         Thread pwmThread = new Thread(pwmController, "PWM Controller " + pin);
94         pwmControllers.put(pin, pwmController);
95         pwmThread.start();
96         Runtime.getRuntime().addShutdownHook(new Thread(() -> {
97             pwmController.requestStop();
98             try {
99                 pwmThread.join();
100            } catch (InterruptedException e) {
101                Thread.currentThread().interrupt();
102            }
103        }));
104    }
105
106    public static void myPrintln(String tempText) {
107        Console console = new Console();
108        console.println("\u001B[32m" + tempText + "\u001B[0m");
109    }
110
111    public static void main(String[] args) throws Exception {
112        DigitalInput button = pi4j.din().create(PIN_BUTTON);
113        button.addListener(e -> {
114            buttonState = e.state() == DigitalState.LOW ? 1 : 0;
115        });
116        setPwmConfig(PIN_BUZZER);
117        PWMController buzzer = pwmControllers.get(PIN_BUZZER);
118        buzzer.setPwmFrequency(0);
119        buzzer.setPwmDutyCycle(0.5);
120        try {
121            while (true) {
```

```

122         if (buttonState == 1) {
123             myPrintln("buzzer turned on. >>>");
124             buzzer.setPwmFrequency(1000);
125         } else {
126             myPrintln("buzzer turned off. >>>");
127             buzzer.setPwmFrequency(0);
128         }
129         Thread.sleep(100);
130     }
131 }
132 finally {
133     for (PWMController controller : pwmControllers.values()) {
134         controller.requestStop();
135     }
136     pi4j.shutdown();
137 }
138 }
139 }
```

Create a pi4j context for manipulating the GPIOs, and define the GPIO numbers that control the keys and buzzer.

```

private static final Context pi4j = Pi4J.newAutoContext();
private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
private static volatile int buttonState = 0;
private static int PIN_BUTTON = 20;
private static int PIN_BUZZER = 4;
```

Initialize the button input pin, create a monitoring event, and assign the key value to buttonState when the button state changes.

```

DigitalInput button = pi4j.din().create(PIN_BUTTON);
button.addListener(e -> {
    buttonState = e.state() == DigitalState.LOW ? 1 : 0;
});
```

Initialize the PWM pin that controls the passive buzzer.

```

setPwmConfig(PIN_BUZZER);
PWMController buzzer = pwmControllers.get(PIN_BUZZER);
buzzer.setPwmFrequency(0);
buzzer.setPwmDutyCycle(0.5);
```

When buttonState is 1, the passive buzzer sounds, and when buttonState is 0, the buzzer sound is turned off.  
Print the information in the console.

```

if (buttonState == 1) {
    myPrintln("buzzer turned on. >>>");
    buzzer.setPwmFrequency(1000);
} else {
    myPrintln("buzzer turned off. >>>");
    buzzer.setPwmFrequency(0);
}
```

# (Important) Chapter 7 ADC

We have learned how to control the brightness of an LED through PWM and that PWM is not a real analog signal. In this chapter, we will learn how to read analog values via an ADC Module and convert these analog values into digital.

## Project 7.1 Read the Voltage of Potentiometer

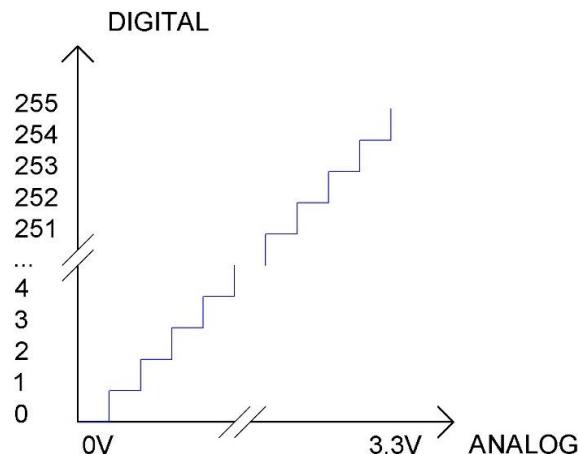
In this project, we will use the ADC function of an ADC Module to read the voltage value of a potentiometer.

### Circuit knowledge

#### ADC

An ADC is an electronic integrated circuit used to convert analog signals such as voltages to digital or binary form consisting of 1s and 0s. The range of our ADC module is 8 bits, that means the resolution is  $2^8=256$ , so that its range (at 3.3V) will be divided equally to 256 parts.

Any analog value can be mapped to one digital value using the resolution of the converter. So the more bits the ADC has, the denser the partition of analog will be and the greater the precision of the resulting conversion.



Subsection 1: the analog in range of 0V-3.3/256 V corresponds to digital 0;

Subsection 2: the analog in range of 3.3 /256 V-2\*3.3 /256V corresponds to digital 1;

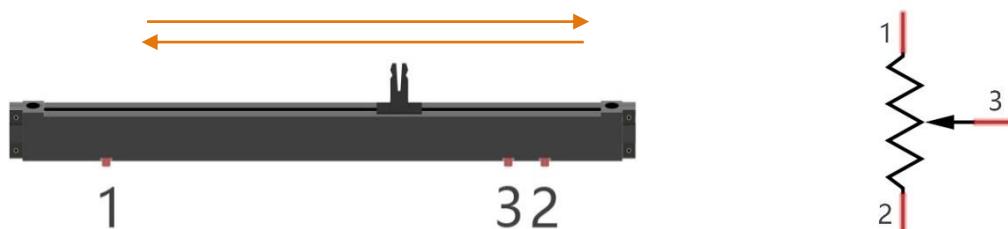
The resultant analog signal will be divided accordingly.



## Component knowledge

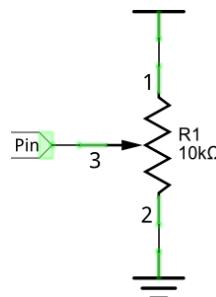
### Potentiometer

Potentiometer is a resistive element with three Terminal parts. Unlike the resistors that we have used thus far in our project which have a fixed resistance value, the resistance value of a potentiometer can be adjusted. A potentiometer is often made up by a resistive substance (a wire or carbon element) and movable contact brush. When the brush moves along the resistor element, there will be a change in the resistance of the potentiometer's output side (3) (or change in the voltage of the circuit that is a part). The illustration below represents a linear sliding potentiometer and its electronic symbol on the right.



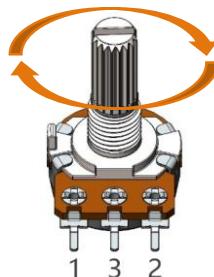
Between potentiometer pin 1 and pin 2 is the resistive element (a resistance wire or carbon) and pin 3 is connected to the brush that makes contact with the resistive element. In our illustration, when the brush moves from pin 1 to pin 2, the resistance value between pin 1 and pin 3 will increase linearly (until it reaches the highest value of the resistive element) and at the same time the resistance between pin 2 and pin 3 will decrease linearly and conversely down to zero. At the midpoint of the slider the measured resistance values between pin 1 and 3 and between pin 2 and 3 will be the same.

In a circuit, both sides of resistive element are often connected to the positive and negative electrodes of power. When you slide the brush "pin 3", you can get variable voltage within the range of the power supply.



### Rotary potentiometer

Rotary potentiometers and linear potentiometers have the same function; the only difference being the physical action being a rotational rather than a sliding movement.



### ADS7830

The ADS7830 is a single-supply, low-power, 8-bit data acquisition device that features a serial I<sup>2</sup>C interface and an 8-channel multiplexer. The following table is the pin definition diagram of ADS7830.

SYMBOL	PIN	DESCRIPTION	TOP VIEW
CH0	1	Analog input channels (A/D converter)	
CH1	2		
CH2	3		
CH3	4		
CH4	5		
CH5	6		
CH6	7		
CH7	8		
GND	9	Ground	
REF in/out	10	Internal +2.5V Reference, External Reference Input	
COM	11	Common to Analog Input Channel	
A0	12	Hardware address	
A1	13		
SCL	14	Serial Clock	
SDA	15	Serial Data	
+VDD	16	Power Supply, 3.3V Nominal	

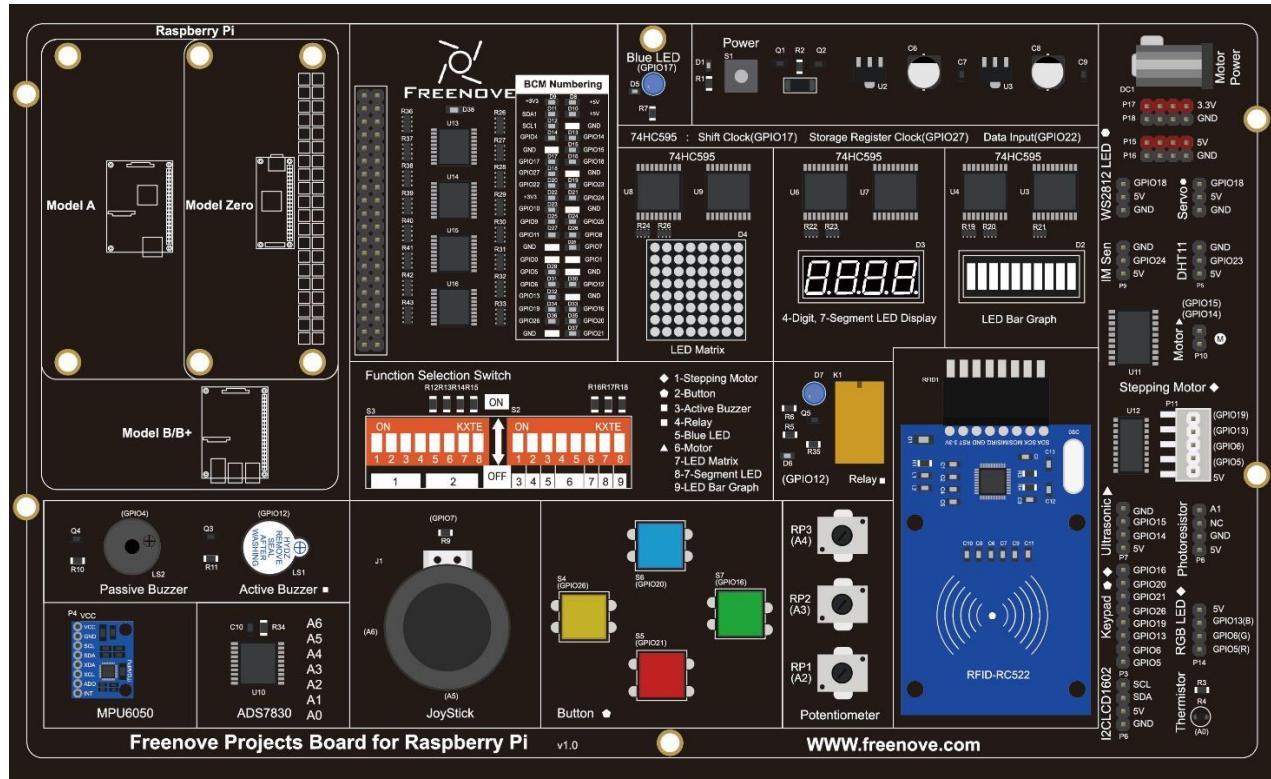
### I<sup>2</sup>C communication

I<sup>2</sup>C (Inter-Integrated Circuit) has a two-wire serial communication mode, which can be used to connect a micro-controller and its peripheral equipment. Devices using I<sup>2</sup>C communications must be connected to the serial data line (SDA), and serial clock line (SCL) (called I<sup>2</sup>C bus). Each device has a unique address that can be used as a transmitter or receiver to communicate with devices connected via the bus.

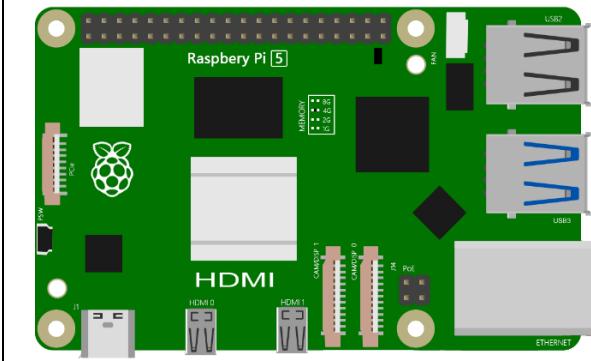


## Component List

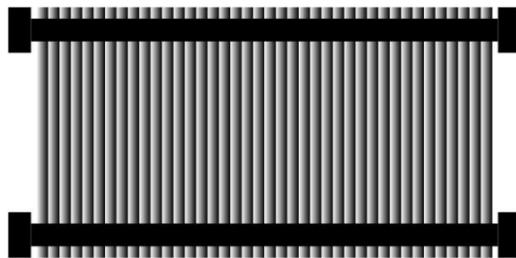
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Raspberry Pi

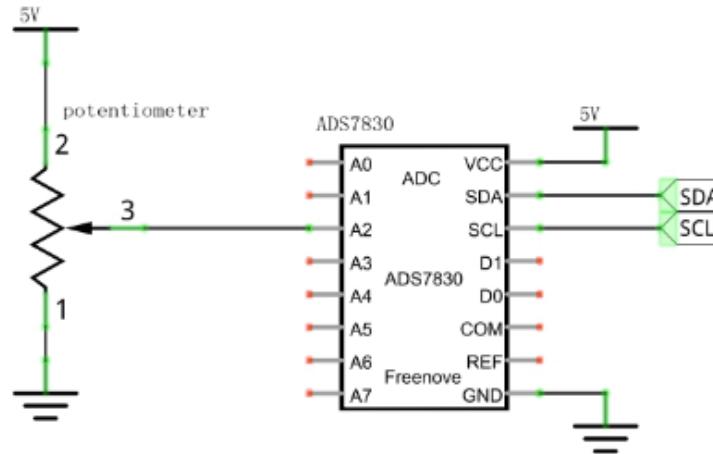


GPIO Ribbon Cable

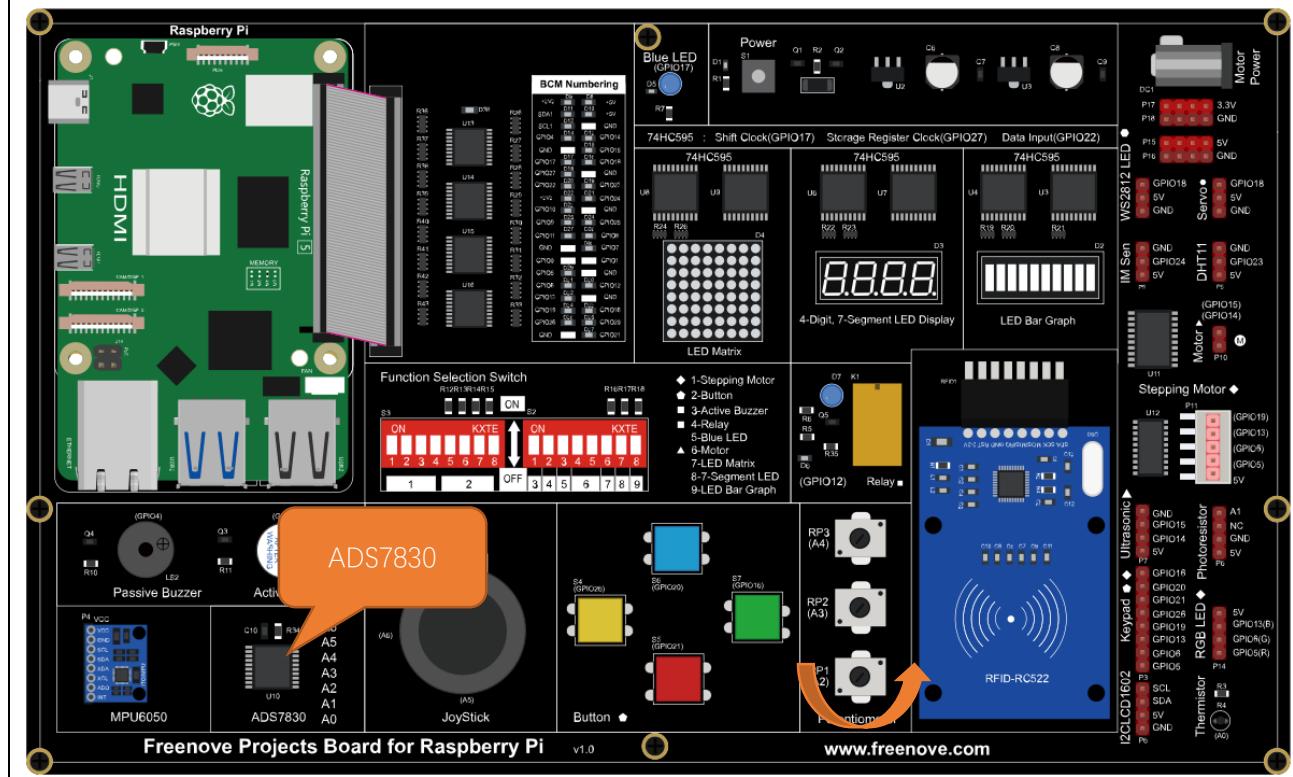


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Configure I2C and Install Smbus

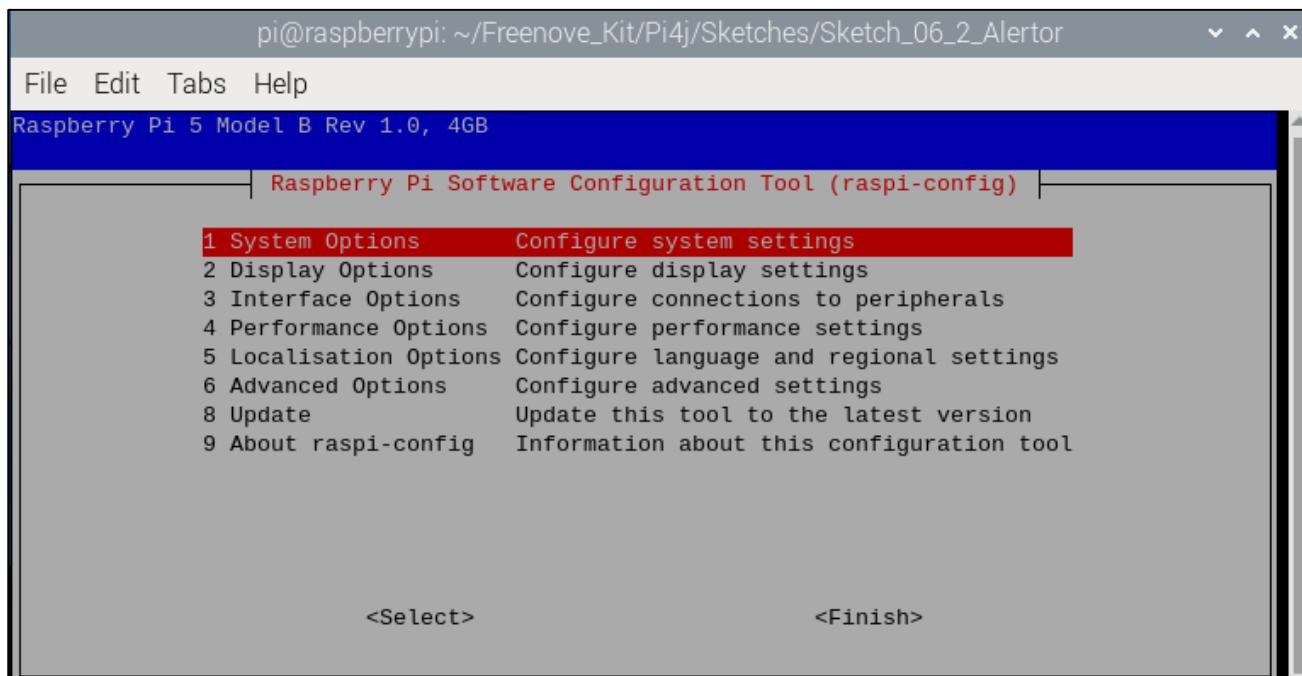
### Enable I2C

The I2C interface in Raspberry Pi is disabled by default. You will need to open it manually and enable the I2C interface as follows:

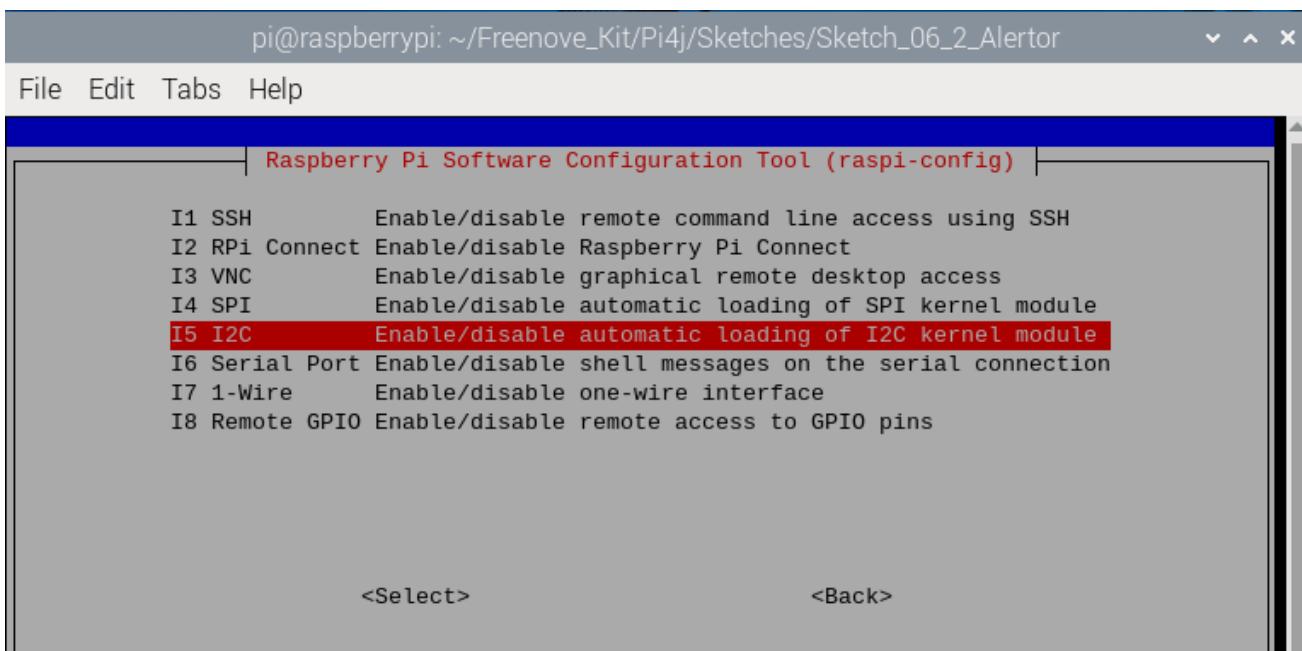
Type command in the Terminal:

```
sudo raspi-config
```

Then open the following dialog box:



Choose “**Interfacing Options**” then “**I5 I2C**” then “**Yes**” and then “**Finish**” in this order and restart your RPi. The I2C module will then be started.



Type a command to check whether the I2C module is started:

```
lsmod | grep i2c
```

If the I2C module has been started, the following content will be shown.

Different models of Raspberry Pi display different contents depending on the CPU installed:

```
pi@raspberrypi:~ $ lsmod | grep i2c
i2c_dev           49152  0
i2c_brcmstb       49152  0
i2c_designware_platform 49152  0
i2c_designware_core 49152  1 i2c_designware_platform
pi@raspberrypi:~ $
```

I2C device address detection:

```
i2cdetect -y 1
```

When you are using the ADS7830 Module, the result should look like this:

```
pi@raspberrypi:~ $ i2cdetect -y 1
      0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:         - - - - - - - - - - - - - - - - - - - -
10:         - - - - - - - - - - - - - - - - - - - -
20:         - - - - - - - - - - - - - - - - - - - -
30:         - - - - - - - - - - - - - - - - - - - -
40:         - - - - - - - - - - 48 - - - - - - - -
50:         - - - - - - - - - - - - - - - - - - - -
60:         - - - - - - - - - - - - - - - - - - - -
70:         - - - - - - - - - - - - - - - - - - - -
pi@raspberrypi:~ $
```

Here, 48 (HEX) is the I2C address of ADC Module (ADS7830).

## Sketch

In this chapter, we will learn the combined usage of ADC and potentiometer.

[Sketch\\_07\\_1\\_ADC](#)

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_07_1_ADC
```

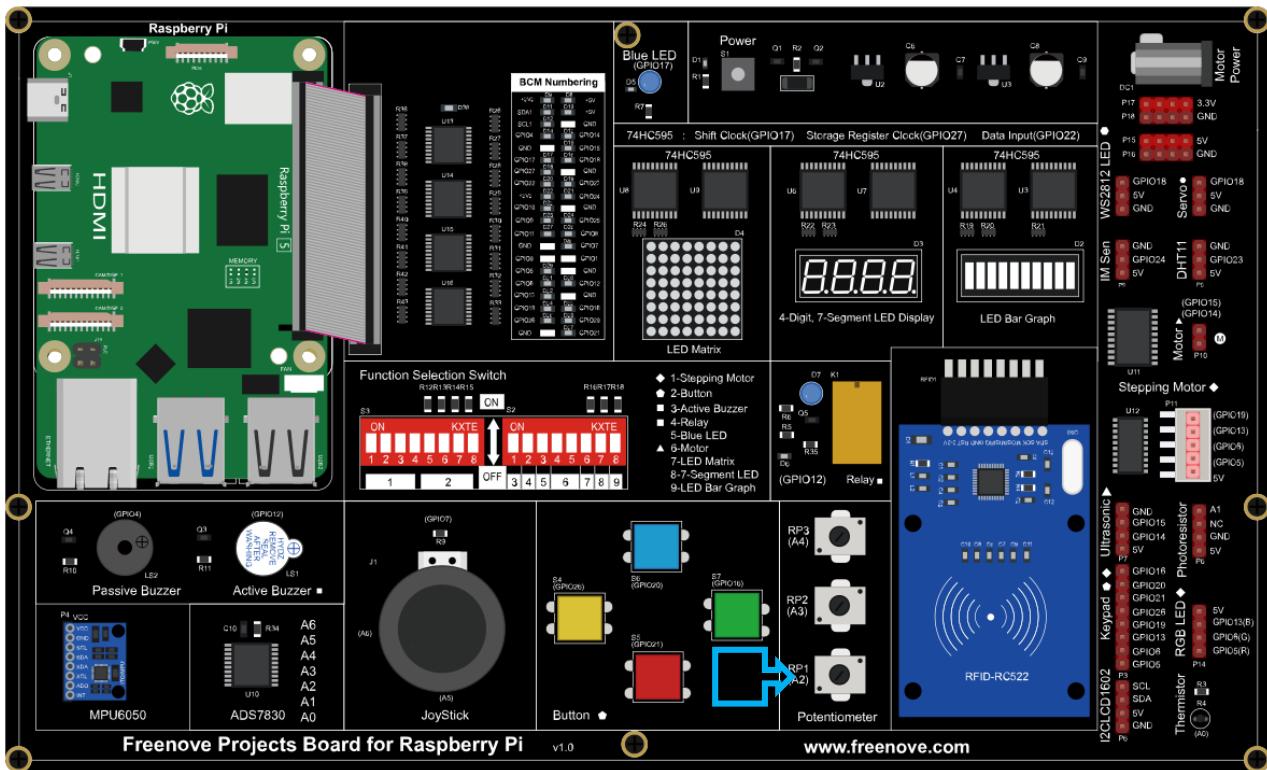
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_07_1_ADC
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_07_1_ADC $
```

Enter the command to run the code.

```
jbang ADC.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_07_1_ADC
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_07_1_ADC $ jbang ADC.java
```

When the code is running, rotate the potentiometer marked below.



You can see that the ADC values change with the rotation of the potentiometer. The value 0 means that the potentiometer's voltage read by ADC is 0V, 255 indicates that the voltage is 5V.

```
pi@raspberrypi: ~/Freenove_Kit/Pi4j/Sketches/Sketch_07_1_ADC
File Edit Tabs Help
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:0
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:0
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:53
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:112
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:162
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:206
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:255
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:255
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:190
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:89
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:16
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value:0
```

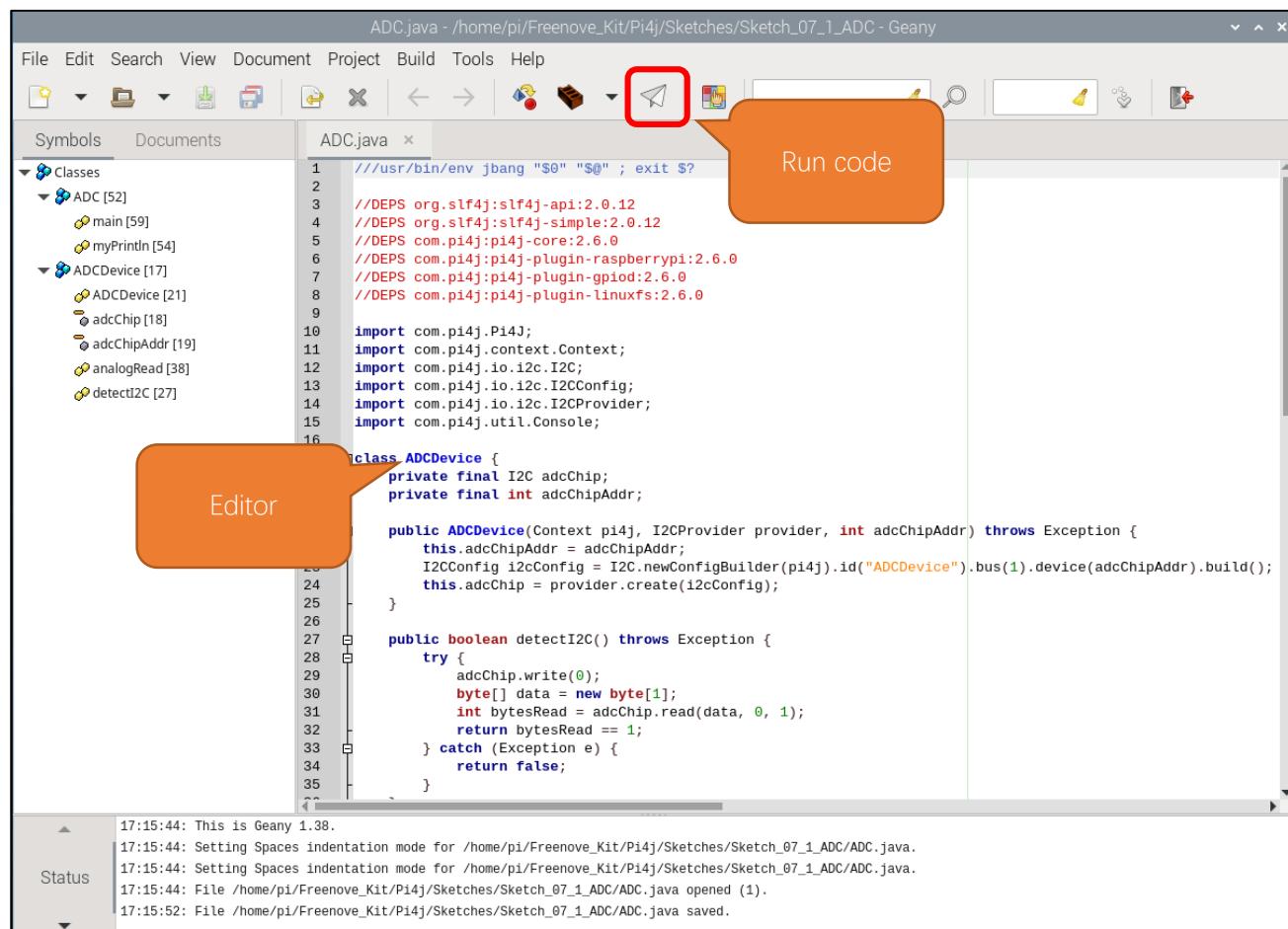
Press Ctrl+C to exit the code.

```
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown.
n. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_07_1_ADC $
```

You can open the code with Geany with the following command to view and edit it.

**geany ADC.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
9
10 import com.pi4j.Pi4J;
11 import com.pi4j.context.Context;
12 import com.pi4j.io.i2c.I2C;
13 import com.pi4j.io.i2c.I2CConfig;
14 import com.pi4j.io.i2c.I2CProvider;

```

```
15 import com.pi4j.util.Console;
16
17 class ADCDevice {
18     private final I2C adcChip;
19     private final int adcChipAddr;
20
21     public ADCDevice(Context pi4j, I2CProvider provider, int adcChipAddr) throws Exception {
22         this.adcChipAddr = adcChipAddr;
23         I2CConfig i2cConfig =
24             I2C.newConfigBuilder(pi4j).id("ADCDevice").bus(1).device(adcChipAddr).build();
25         this.adcChip = provider.create(i2cConfig);
26     }
27
28     public boolean detectI2C() throws Exception {
29         try {
30             adcChip.write(0);
31             byte[] data = new byte[1];
32             int bytesRead = adcChip.read(data, 0, 1);
33             return bytesRead == 1;
34         } catch (Exception e) {
35             return false;
36         }
37     }
38
39     public int analogRead(int chn) {
40         byte command = (byte) (0x84 | (((chn << 2 | chn >> 1) & 0x07) << 4));
41         adcChip.write(command);
42         byte[] data = new byte[1];
43         int bytesRead = adcChip.read(data, 0, 1);
44         if (bytesRead == 1) {
45             int adcValue = data[0] & 0xFF;
46             return adcValue;
47         } else {
48             return -1;
49         }
50     }
51
52     public class ADC{
53
54         public static void myPrintln(String format, Object... args) {
55             Console console = new Console();
56             console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
57         }
58     }
59 }
```

```

58
59     public static void main(String[] args) throws Exception {
60         Context pi4j = Pi4J.newAutoContext();
61         I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
62         try {
63             int ADC_CHIP_ADDR = 0x48;
64             ADCDevice adcDevice = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
65             if (adcDevice.detectI2C()) {
66                 int ADC_CHANNEL = 2;
67                 while (true) {
68                     int adcValue = adcDevice.analogRead(ADC_CHANNEL);
69                     if (adcValue != -1) {
70                         myPrintln("ADC Channel %d Value:%d", ADC_CHANNEL, adcValue);
71                     } else {
72                         myPrintln("Failed to read data from ADC.");
73                     }
74                     Thread.sleep(100);
75                 }
76             } else {
77                 myPrintln("ADS7830 device not detected at address 0x" +
78                         Integer.toHexString(ADC_CHIP_ADDR));
79             }
80         } finally {
81             pi4j.shutdown();
82         }
83     }
84 }
```

Dependency declaration, these libraries will be automatically downloaded by jbang at runtime and added to the classpath.

```
//DEPS org.slf4j:slf4j-api:2.0.12
//DEPS org.slf4j:slf4j-simple:2.0.12
//DEPS com.pi4j:pi4j-core:2.6.0
//DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
//DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
//DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
```

Import I2C library. In this project, we use I2C to read the channel value of ADS7830.

```
import com.pi4j.Pi4J;
import com.pi4j.context.Context;
import com.pi4j.io.i2c.I2C;
import com.pi4j.io.i2c.I2CConfig;
import com.pi4j.io.i2c.I2CProvider;
import com.pi4j.util.Console;
```

Constructor of ADCDevice class, which is used to initialize I2C bus to facilitate later reading and writing ADS7830 chip.

```
public ADCDevice(Context pi4j, I2CProvider provider, int adcChipAddr) throws Exception {
    this.adcChipAddr = adcChipAddr;
    I2CConfig i2cConfig =
        I2C.newConfigBuilder(pi4j).id("ADCDevice").bus(1).device(adcChipAddr).build();
    this.adcChip = provider.create(i2cConfig);
}
```

Write a byte to the target chip, and then read the data. If the data can be read, it means the target chip exists and communication is successful. If an I2C exception is detected, it means the target chip does not exist.

```
public boolean detectI2C() throws Exception {
    try {
        adcChip.write(0);
        byte[] data = new byte[1];
        int bytesRead = adcChip.read(data, 0, 1);
        return bytesRead == 1;
    } catch (Exception e) {
        return false;
    }
}
```

Write the read command to the ADS7830 and read the corresponding ADC value. It is returned by the return value.

```
public int analogRead(int chn) {
    byte command = (byte) (0x84 | (((chn << 2 | chn >> 1) & 0x07) << 4));
    adcChip.write(command);
    byte[] data = new byte[1];
    int bytesRead = adcChip.read(data, 0, 1);
    if (bytesRead == 1) {
        int adcValue = data[0] & 0xFF;
        return adcValue;
    } else {
        return -1;
    }
}
```

Create a pi4j context to get the Raspberry Pi i2c interface.

```
Context pi4j = Pi4J.newAutoContext();
I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
```

The I2C address of the ADS7830 is 0x48.

Create an ADCDevice class, associate it with the Raspberry PI I2C interface, and assign a value to the adcDevice.

```
int ADC_CHIP_ADDR = 0x48;  
ADCDevice adcDevice = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
```

Check whether the chip can communicate normally. If the communication is successful, read channel 2 of the ADS7830 chip and print it out in the terminal.

```
if (adcDevice.detectI2C()) {  
    int ADC_CHANNEL = 2;  
    while (true) {  
        int adcValue = adcDevice.analogRead(ADC_CHANNEL);  
        if (adcValue != -1) {  
            myPrintln("ADC Channel %d Value:%d", ADC_CHANNEL, adcValue);  
        } else {  
            myPrintln("Failed to read data from ADC.");  
        }  
        Thread.sleep(100);  
    }  
}
```

If communication with the chip fails, a prompt message is printed on the terminal.

```
else {  
    myPrintln("ADS7830 device not detected at address 0x" +  
    Integer.toHexString(ADC_CHIP_ADDR));  
}
```

When the code finishes running, close the Pi4J context.

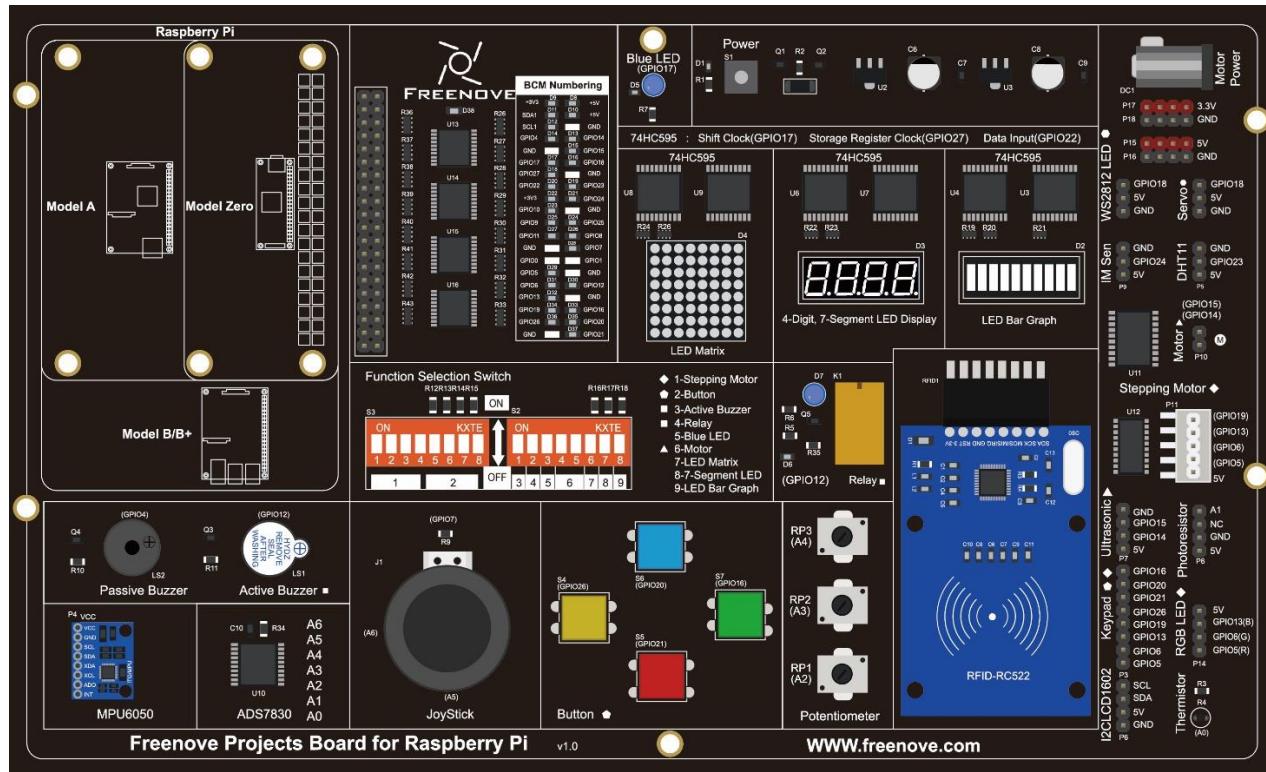
```
finally {  
    pi4j.shutdown();  
}
```

## Project 7.2 Soft Light

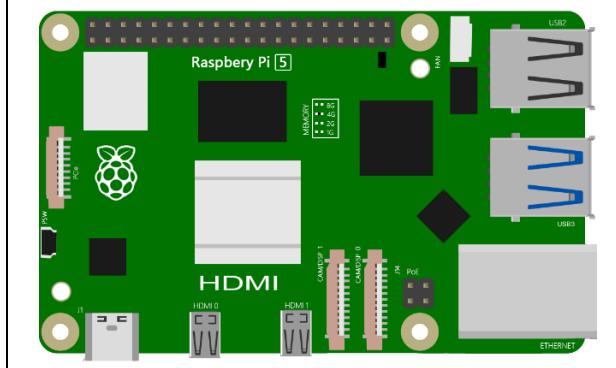
In this project, we will make a soft light. We will use an ADC Module to read ADC values of a potentiometer and map it to duty cycle ratio of the PWM used to control the brightness of an LED. Then you can change the brightness of an LED by adjusting the potentiometer.

### Component List

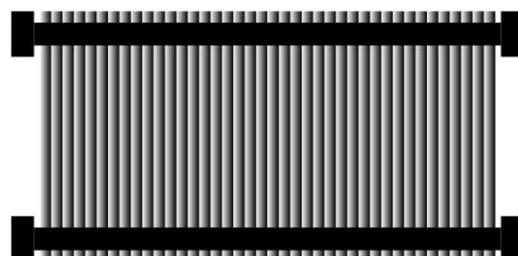
Freenove Projects Board for Raspberry Pi



Raspberry Pi

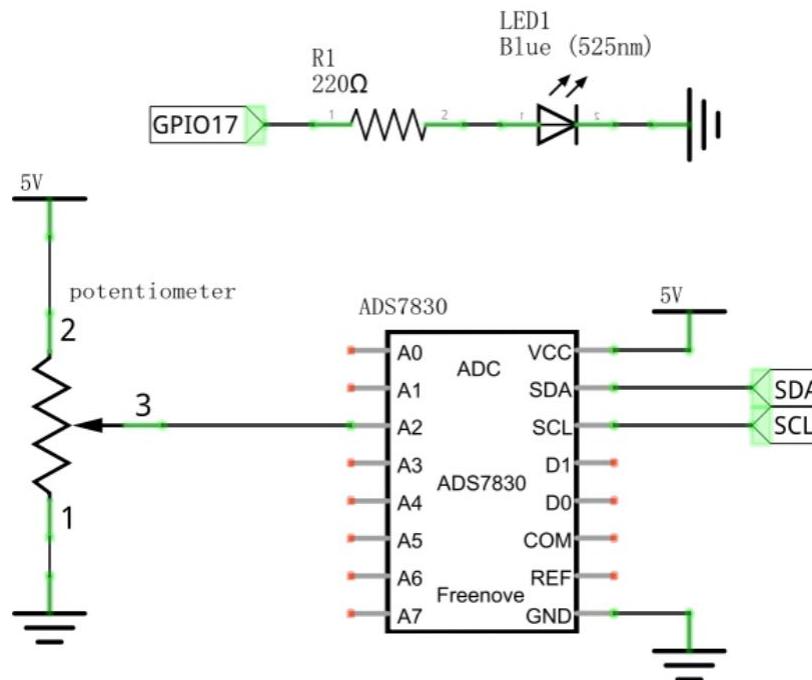


GPIO Ribbon Cable

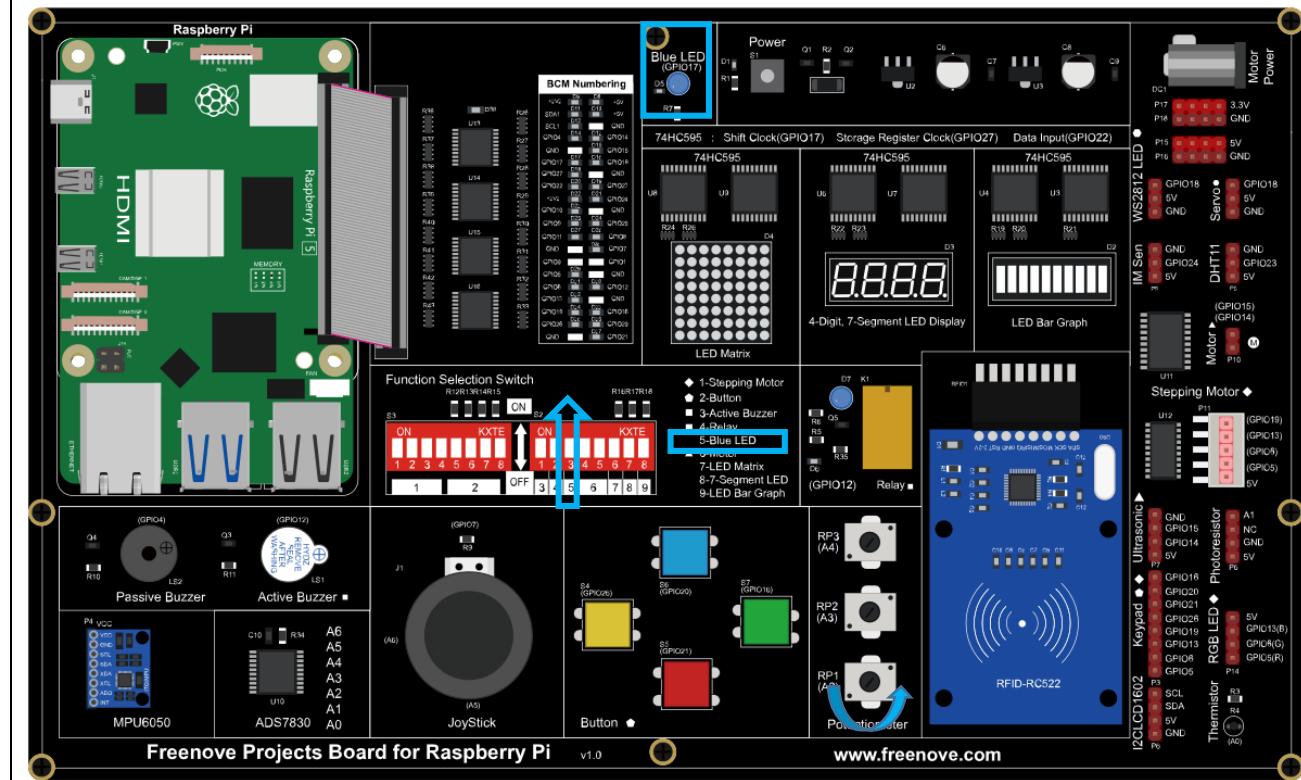


## Circuit

Schematic diagram



Hardware connection



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this project, we learn how to control the brightness of LED with the potentiometer.

### Sketch\_07\_2\_Softlight

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_07_2_Softlight
```

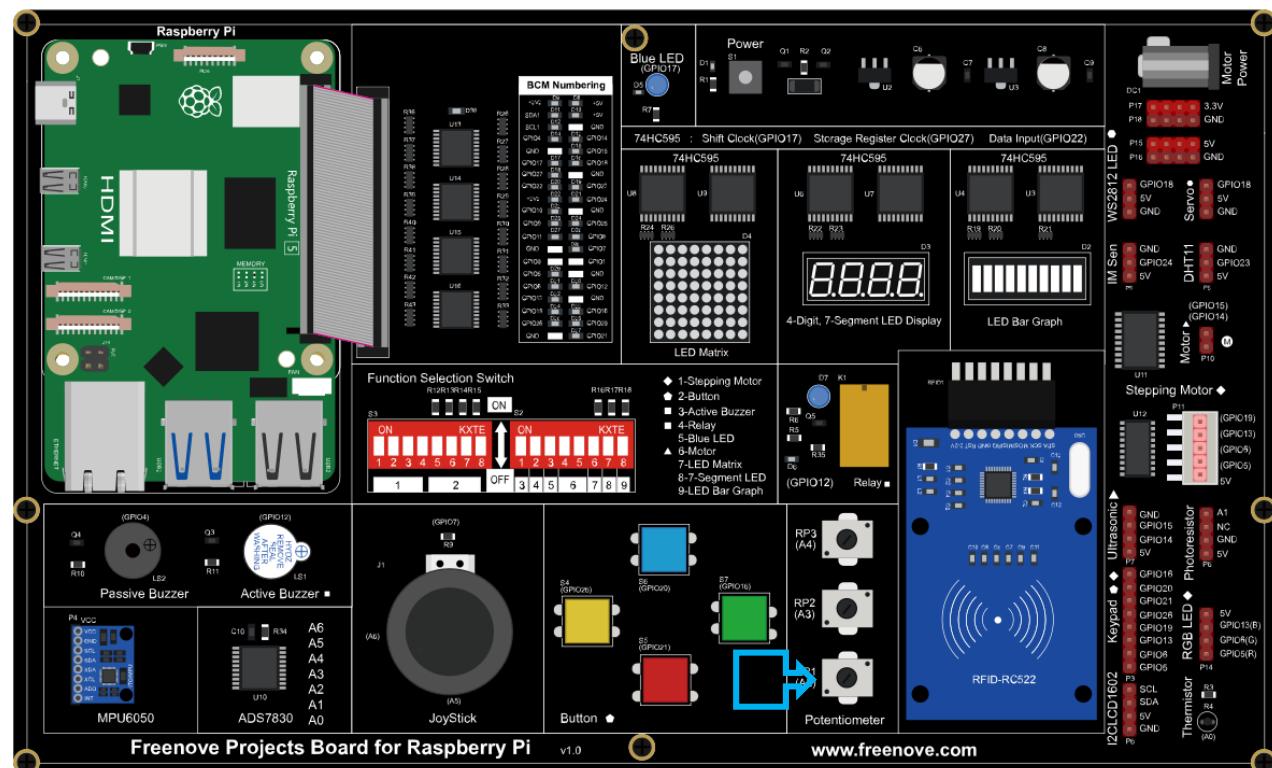
```
pi@raspberrypi:~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_07_2_Softlight/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_07_2_Softlight $
```

Enter the command to run code.

```
jbang Softlight.java
```

```
pi@raspberrypi:~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_07_2_Softlight/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_07_2_Softlight $ jbang Softlight.java
```

When the code is running, turn the potentiometer marked below and you can see the brightness of the LED change.



On the Terminal, you can see the printed ADC values and the calculated voltage values.

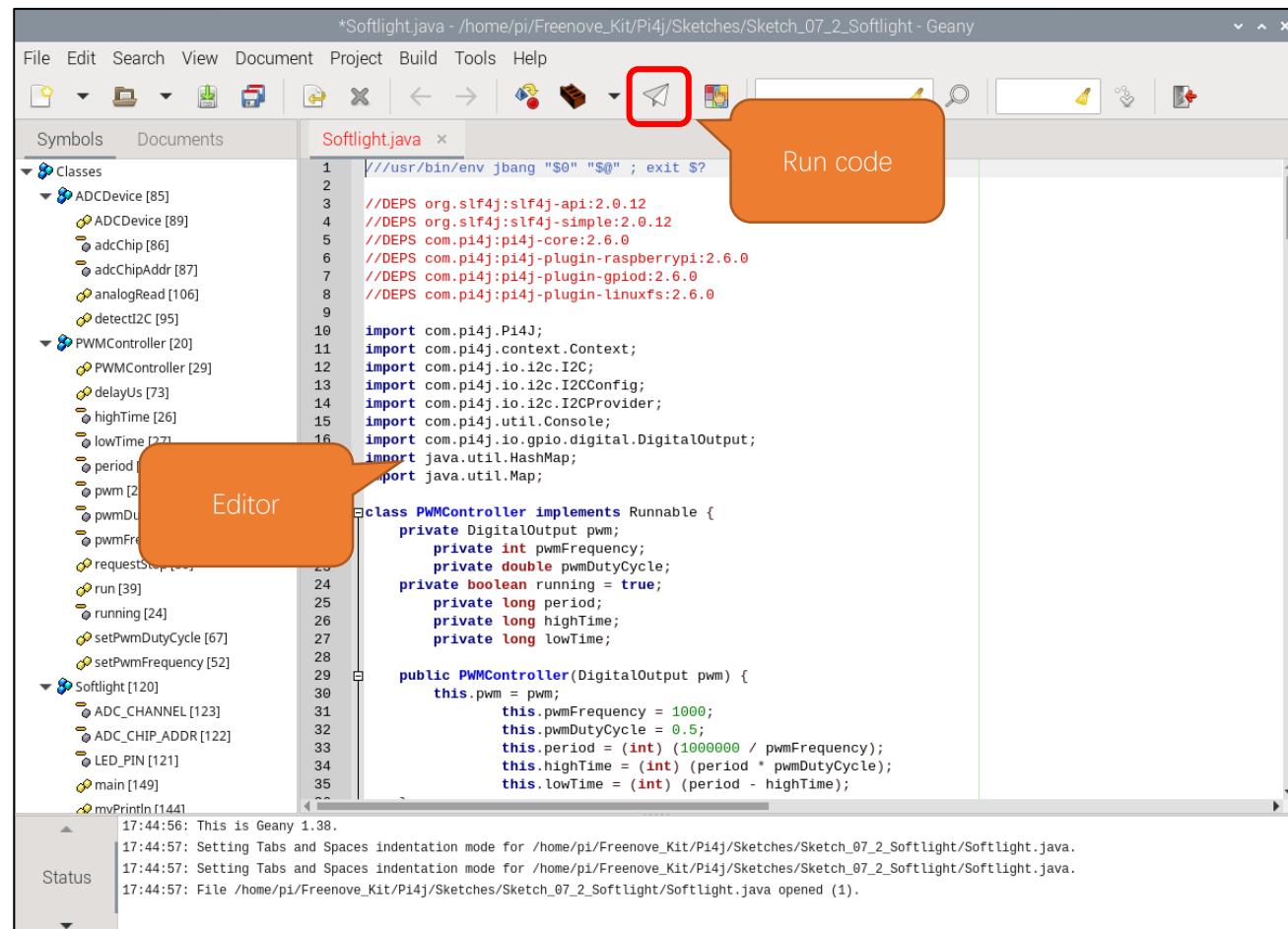
```
[main] INFO com.pi4j.util.Console - ADC value:92, Voltage:1.80V
```

Press Ctrl+C to exit the program.

You can open the code with Geany with the following command to view and edit it.

### geany Softlight.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
9
10 import com.pi4j.Pi4J;
11 import com.pi4j.context.Context;
12 import com.pi4j.io.i2c.I2C;
13 import com.pi4j.io.i2c.I2CConfig;
14 import com.pi4j.io.i2c.I2CProvider;
```



```
15 import com.pi4j.util.Console;
16 import com.pi4j.io.gpio.digital.DigitalOutput;
17 import java.util.HashMap;
18 import java.util.Map;
19
20 class PWMController implements Runnable {
...
21     .....
83 }
84
85 class ADCDevice {
...
86     .....
118 }
119
120 public class Softlight{
121     private static int LED_PIN = 17;
122     private static int ADC_CHIP_ADDR = 0x48;
123     private static int ADC_CHANNEL = 2;
124
125     private static final Context pi4j = Pi4J.newAutoContext();
126     private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
127
128     public static void setPwmConfig(int pin) throws Exception {
129         DigitalOutput pwm = pi4j.dout().create(pin);
130         PWMController pwmController = new PWMController(pwm);
131         Thread pwmThread = new Thread(pwmController, "PWM Controller " + pin);
132         pwmControllers.put(pin, pwmController);
133         pwmThread.start();
134         Runtime.getRuntime().addShutdownHook(new Thread(() -> {
135             pwmController.requestStop();
136             try {
137                 pwmThread.join();
138             } catch (InterruptedException e) {
139                 Thread.currentThread().interrupt();
140             }
141         }));
142     }
143
144     public static void myPrintln(String format, Object... args) {
145         Console console = new Console();
146         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
147     }
148
149     public static void main(String[] args) throws Exception {
150         Context pi4j = Pi4J.newAutoContext();
```

```

151 I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
152 setPwmConfig(LED_PIN);
153 PWMController led = pwmControllers.get(LED_PIN);
154
155 try {
156     ADCDevice adc = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
157     if (adc.detectI2C()) {
158         while (true) {
159             int adcValue = adc.analogRead(ADC_CHANNEL);
160             if (adcValue != -1) {
161                 led.setPwmDutyCycle(((double)adcValue/255.0));
162                 double voltage = (double)adcValue / 255.0 * 5.0;
163                 myPrintln("ADC value:%d, Voltage:%.2fV", adcValue, voltage);
164             } else {
165                 myPrintln("Failed to read data from ADC.");
166             }
167             Thread.sleep(100);
168         }
169     } else {
170         myPrintln("ADS7830 device not detected at address 0x" +
171             Integer.toHexString(ADC_CHIP_ADDR));
172     } finally {
173         pi4j.shutdown();
174     }
175 }
176 }
```

The ADC value of the potentiometer is obtained every 100 milliseconds and printed on the terminal. Meanwhile, the ADC value is converted into the duty cycle value of the LED to control the brightness of the LED.

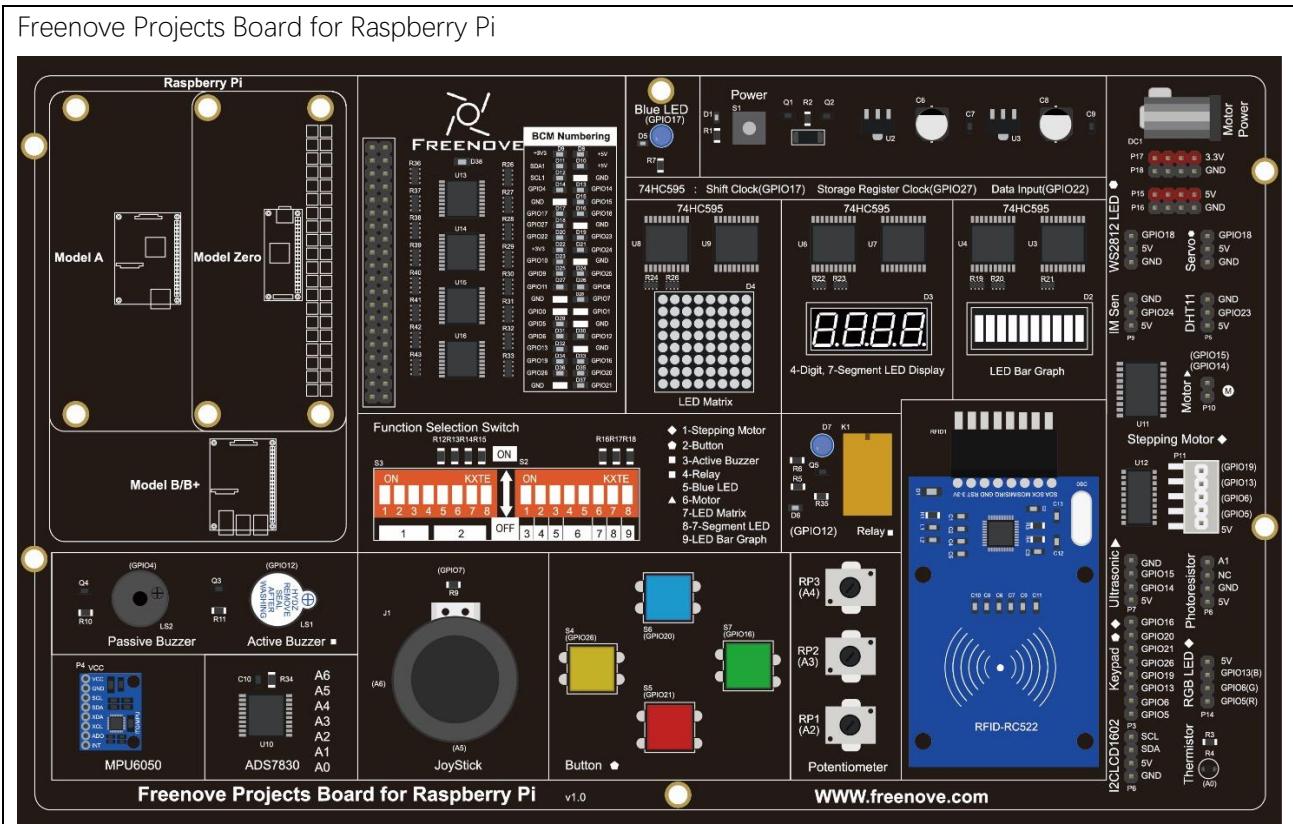
```

while (true) {
    int adcValue = adc.analogRead(ADC_CHANNEL);
    if (adcValue != -1) {
        led.setPwmDutyCycle(((double)adcValue/255.0));
        double voltage = (double)adcValue / 255.0 * 5.0;
        myPrintln("ADC value:%d, Voltage:%.2fV", adcValue, voltage);
    } else {
        myPrintln("Failed to read data from ADC.");
    }
    Thread.sleep(100);
}
```

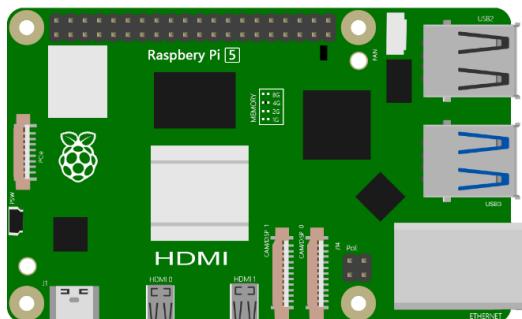
## Project 7.3 Colorful Light

In this project, 3 potentiometers are used to control the RGB LED and in principle, it is the same as with the 'Soft Light' project. Namely, read the voltage value of the potentiometer and then convert it to PWM used to control LED brightness. Difference is that the previous soft light project needed only one LED while this one required (3) RGB LEDs.

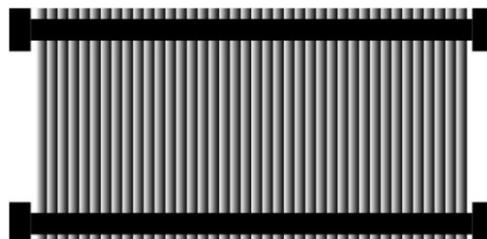
### Component List



Raspberry Pi



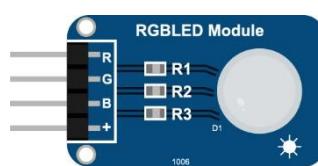
GPIO Ribbon Cable



Jumper Wire

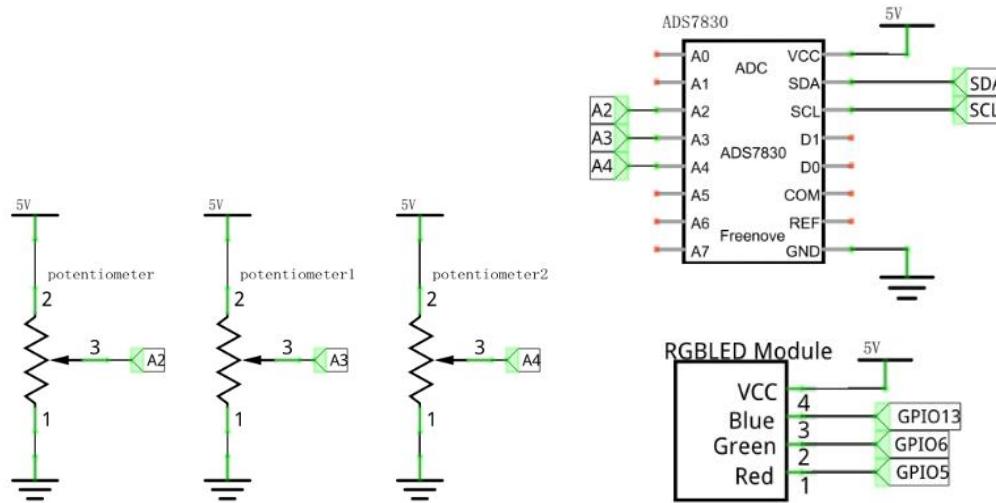


RGBLED Module

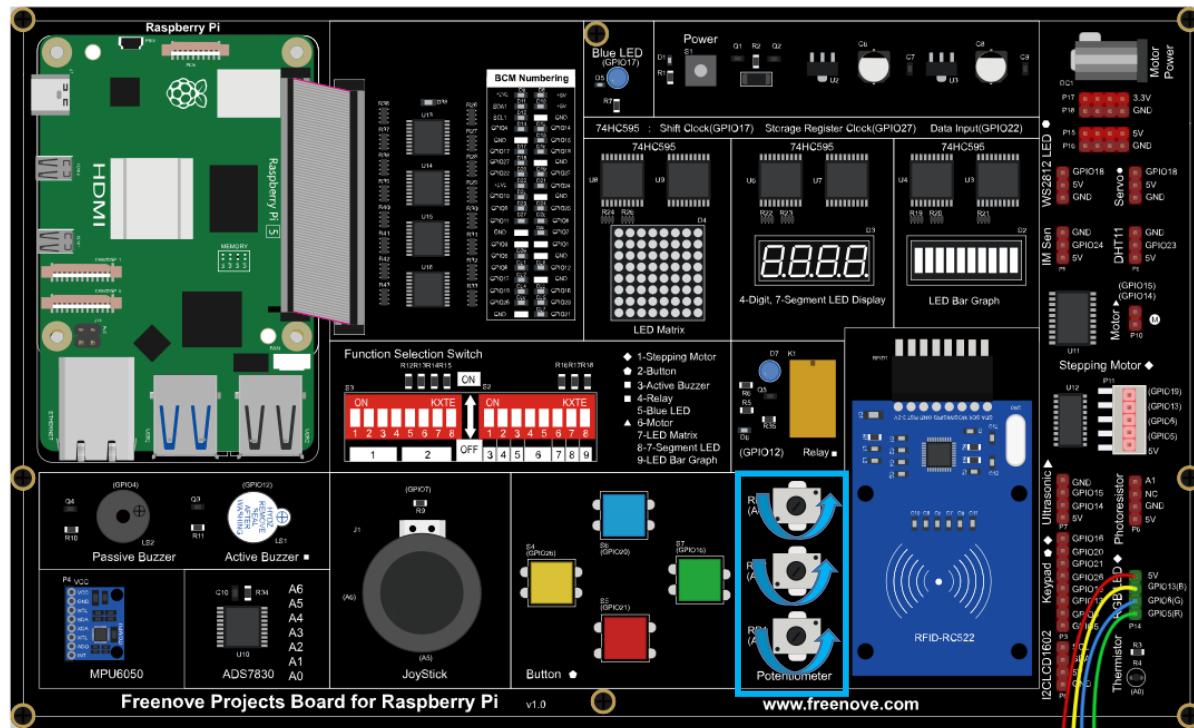


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this project, we learn to use the potentiometer to control the color and brightness of the RGB LED.

### Sketch\_07\_3\_ColorfulSoftlight

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_07_3_ColorfulSoftlight
```

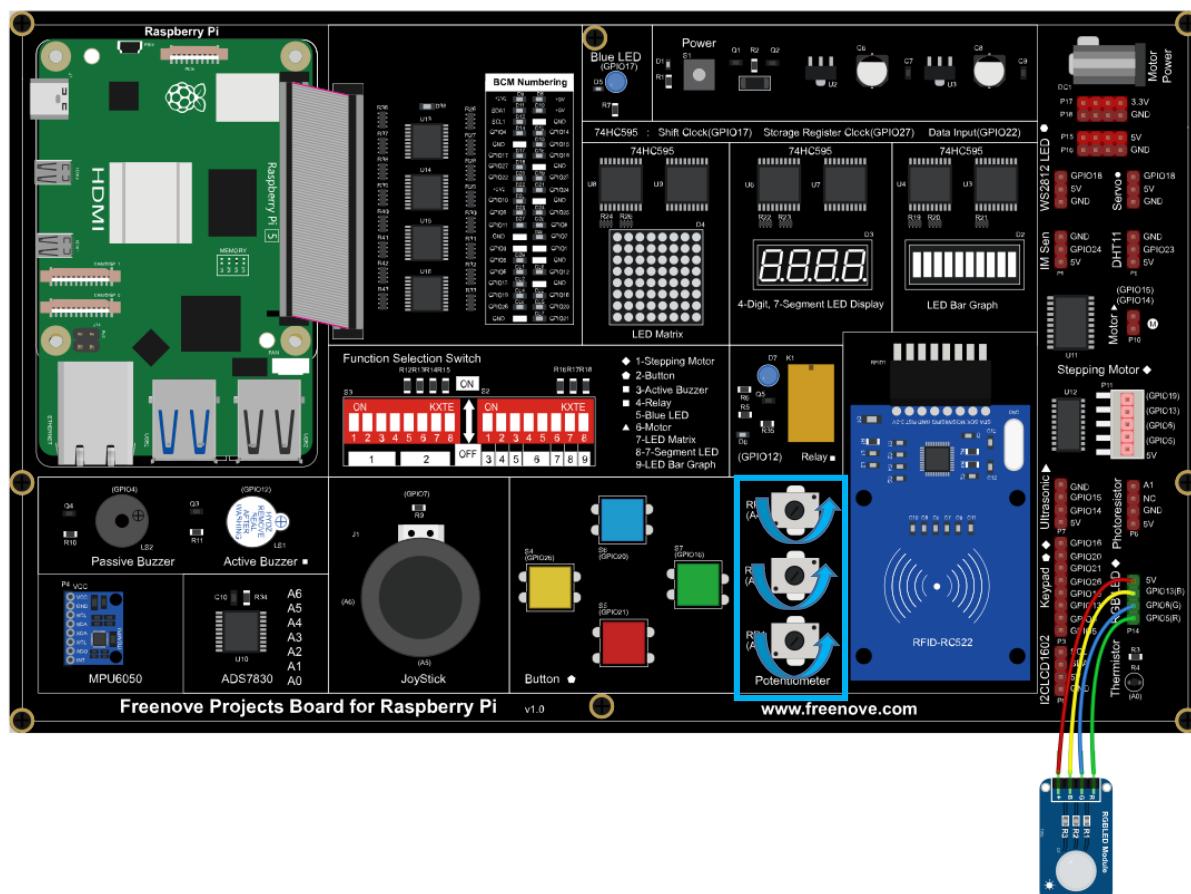
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_07_3_ColorfulSoftlight
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_07_3_ColorfulSoftlight $
```

Enter the command to run the code.

```
jbang ColorfulSoftlight.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_07_3_ColorfulSoftlight
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_07_3_ColorfulSoftlight $ jbang ColorfulSoftlight.java
```

When the code is running, rotate the three potentiometers marked below, you will see the RGB LED's color and brightness change.



The ADC value is printed on the terminal.

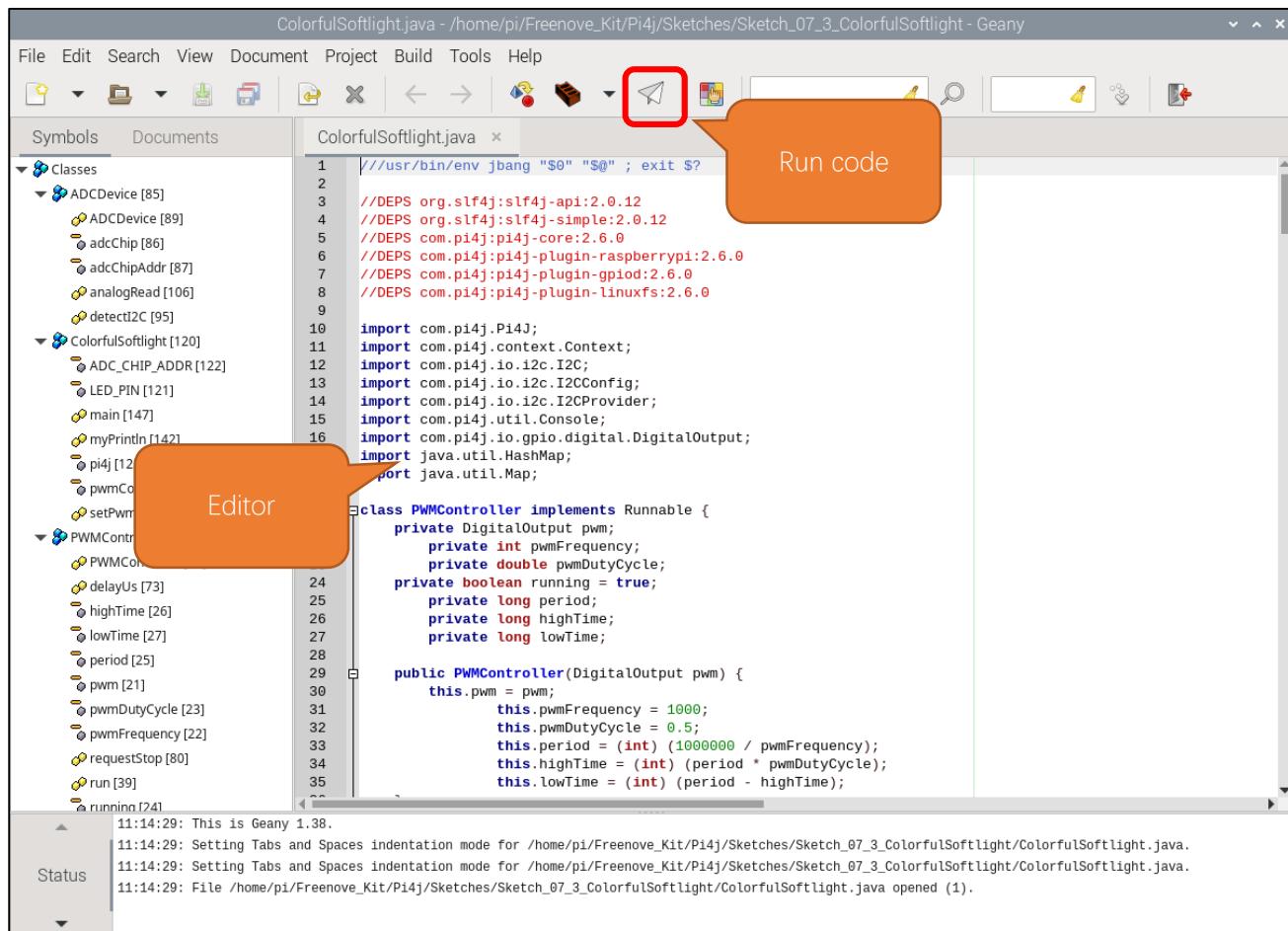
```
[main] INFO com.pi4j.util.Console - ADC value val_Red:132, val_Green:127, val_Blue:144
[main] INFO com.pi4j.util.Console - ADC value val_Red:132, val_Green:127, val_Blue:144
[main] INFO com.pi4j.util.Console - ADC value val_Red:131, val_Green:127, val_Blue:144
[main] INFO com.pi4j.util.Console - ADC value val_Red:132, val_Green:127, val_Blue:144
[main] INFO com.pi4j.util.Console - ADC value val_Red:132, val_Green:127, val_Blue:144
[main] INFO com.pi4j.util.Console - ADC value val_Red:132, val_Green:127, val_Blue:143
[main] INFO com.pi4j.util.Console - ADC value val_Red:132, val_Green:127, val_Blue:144
```

Press Ctrl+C to exit the program.

You can open the code with Geany with the following command to view and edit it.

geany ColorfulSoftlight.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
9
10 import com.pi4j.Pi4J;
11 import com.pi4j.context.Context;
12 import com.pi4j.io.i2c.I2C;
13 import com.pi4j.io.i2c.I2CConfig;
14 import com.pi4j.io.i2c.I2CProvider;
```



```
15 import com.pi4j.util.Console;
16 import com.pi4j.io.gpio.digital.DigitalOutput;
17 import java.util.HashMap;
18 import java.util.Map;
19
20 class PWMController implements Runnable {
...
21     .....
83 }
84
85 class ADCDevice {
...
86     .....
118 }
119
120 public class ColorfulSoftlight{
121     private static int LED_PIN = 17;
122     private static int ADC_CHIP_ADDR = 0x48;
123     private static final Context pi4j = Pi4J.newAutoContext();
124     private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
125
126     public static void setPwmConfig(int pin) throws Exception {
127         DigitalOutput pwm = pi4j.dout().create(pin);
128         PWMController pwmController = new PWMController(pwm);
129         Thread pwmThread = new Thread(pwmController, "PWM Controller " + pin);
130         pwmControllers.put(pin, pwmController);
131         pwmThread.start();
132         Runtime.getRuntime().addShutdownHook(new Thread(() -> {
133             pwmController.requestStop();
134             try {
135                 pwmThread.join();
136             } catch (InterruptedException e) {
137                 Thread.currentThread().interrupt();
138             }
139         }));
140     }
141
142     public static void myPrintln(String format, Object... args) {
143         Console console = new Console();
144         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
145     }
146
147     public static void main(String[] args) throws Exception {
148         Context pi4j = Pi4J.newAutoContext();
149         I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
150 }
```

```

151     int[] ADC_CHN = {2, 3, 4};
152     int[] LED_PINS = {5, 6, 13};
153     for (int pin : LED_PINS) {
154         setPwmConfig(pin);
155     }
156     PWMController red_led = pwmControllers.get(LED_PINS[0]);
157     PWMController green_led = pwmControllers.get(LED_PINS[1]);
158     PWMController blue_led = pwmControllers.get(LED_PINS[2]);
159
160     try {
161         ADCDevice adc = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
162         if (adc.detectI2C()) {
163             while (true) {
164                 int val_Red = adc.analogRead(ADC_CHN[0]);
165                 int val_Green = adc.analogRead(ADC_CHN[1]);
166                 int val_Blue = adc.analogRead(ADC_CHN[2]);
167
168                 red_led.setPwmDutyCycle(1-(double)(val_Red/255.0));
169                 green_led.setPwmDutyCycle(1-(double)(val_Green/255.0));
170                 blue_led.setPwmDutyCycle(1-(double)(val_Blue/255.0));
171
172                 myPrintln("ADC value val_Red:%d, val_Green:%d, val_Blue:%d", val_Red,
173                           val_Green, val_Blue);
174                 Thread.sleep(100);
175             }
176         } else {
177             myPrintln("ADS7830 device not detected at address 0x" +
178                     Integer.toHexString(ADC_CHIP_ADDR));
179         }
180     } finally {
181         pi4j.shutdown();
182     }
183 }
```

Initialize the pins that control the RGB LED.

```

int[] LED_PINS = {5, 6, 13};
for (int pin : LED_PINS) {
    setPwmConfig(pin);
}
PWMController red_led = pwmControllers.get(LED_PINS[0]);
PWMController green_led = pwmControllers.get(LED_PINS[1]);
PWMController blue_led = pwmControllers.get(LED_PINS[2]);
```

Get the ADC values corresponding to the 3 rotentiometers every 100 milliseconds; convert the values into duty cycle values corresponding to PWM, and print prompt information on the terminal.

```
while (true) {  
    int val_Red = adc.analogRead(ADC_CHN[0]);  
    int val_Green = adc.analogRead(ADC_CHN[1]);  
    int val_Blue = adc.analogRead(ADC_CHN[2]);  
  
    red_led.setPwmDutyCycle(1-(double)(val_Red/255.0));  
    green_led.setPwmDutyCycle(1-(double)(val_Green/255.0));  
    blue_led.setPwmDutyCycle(1-(double)(val_Blue/255.0));  
  
    myPrintln("ADC value val_Red:%d, val_Green:%d, val_Blue:%d", val_Red,  
    val_Green, val_Blue);  
    Thread.sleep(100);  
}
```

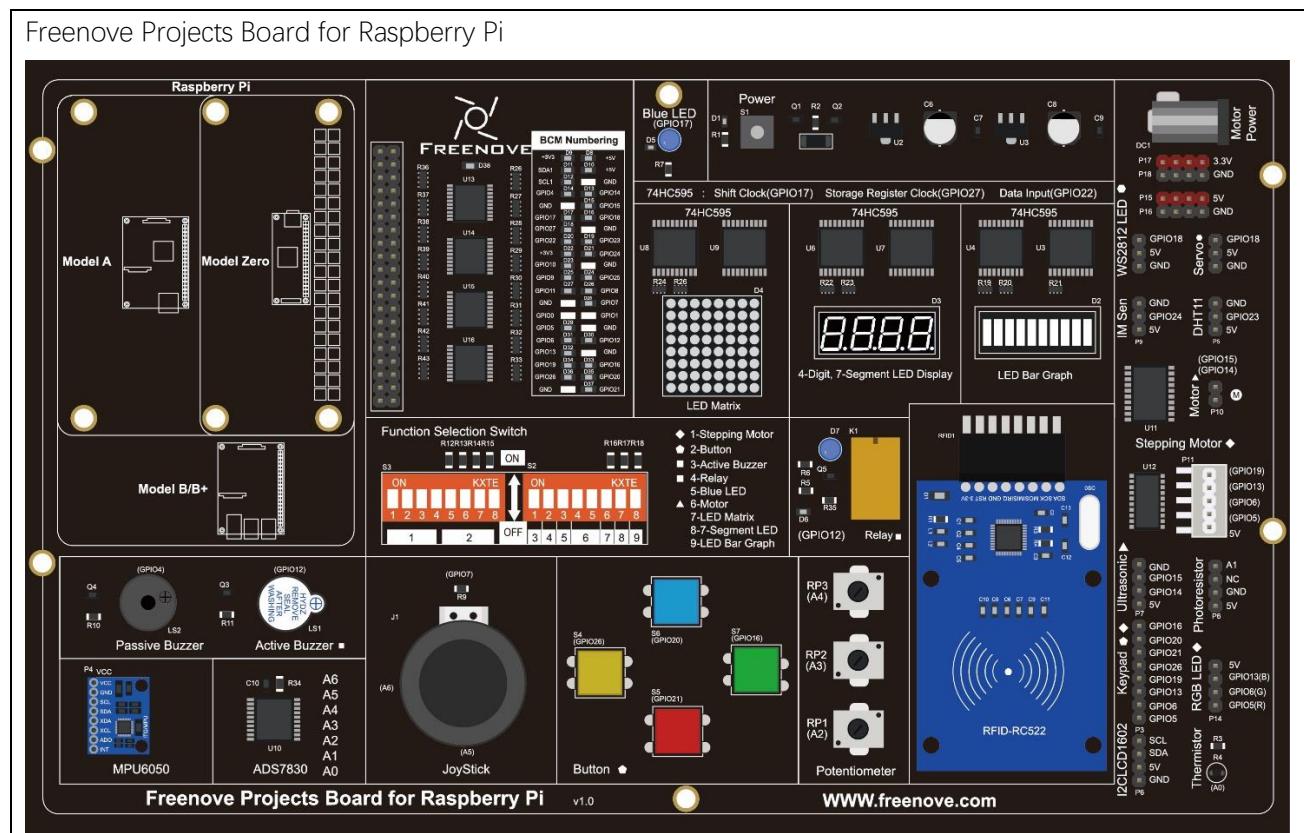
# Chapter 8 Photoresistor & LED

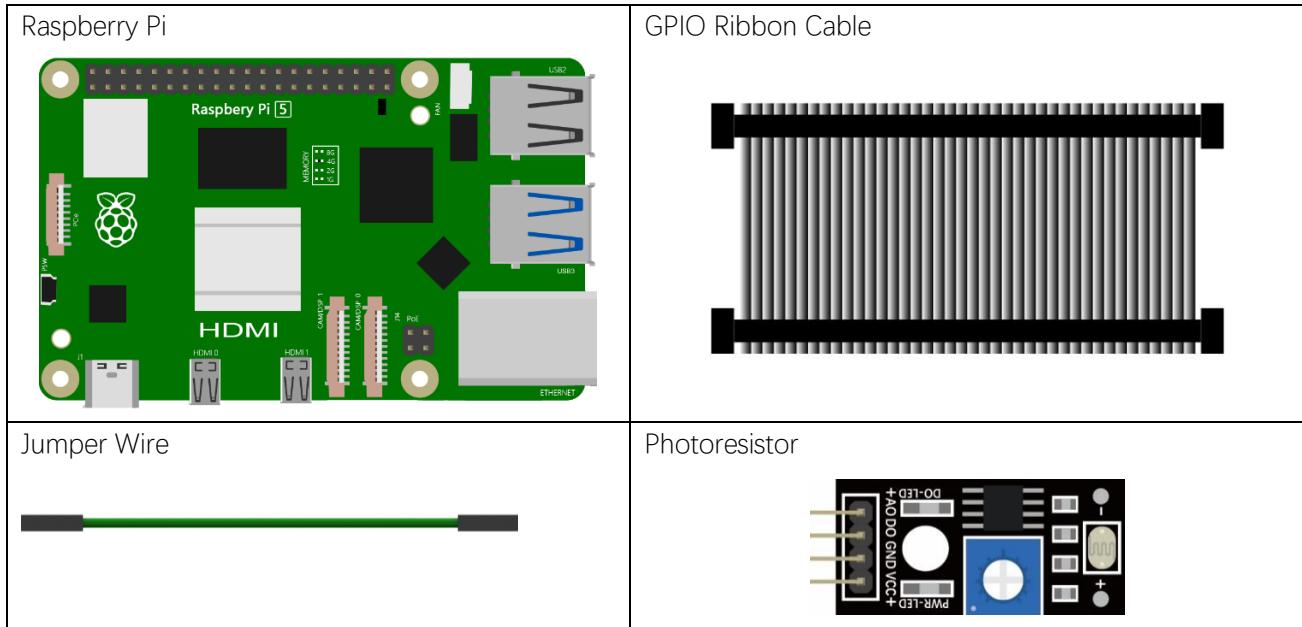
In this chapter, we will learn how to use a photoresistor to make an automatic dimming nightlight.

## Project 8.1 NightLamp

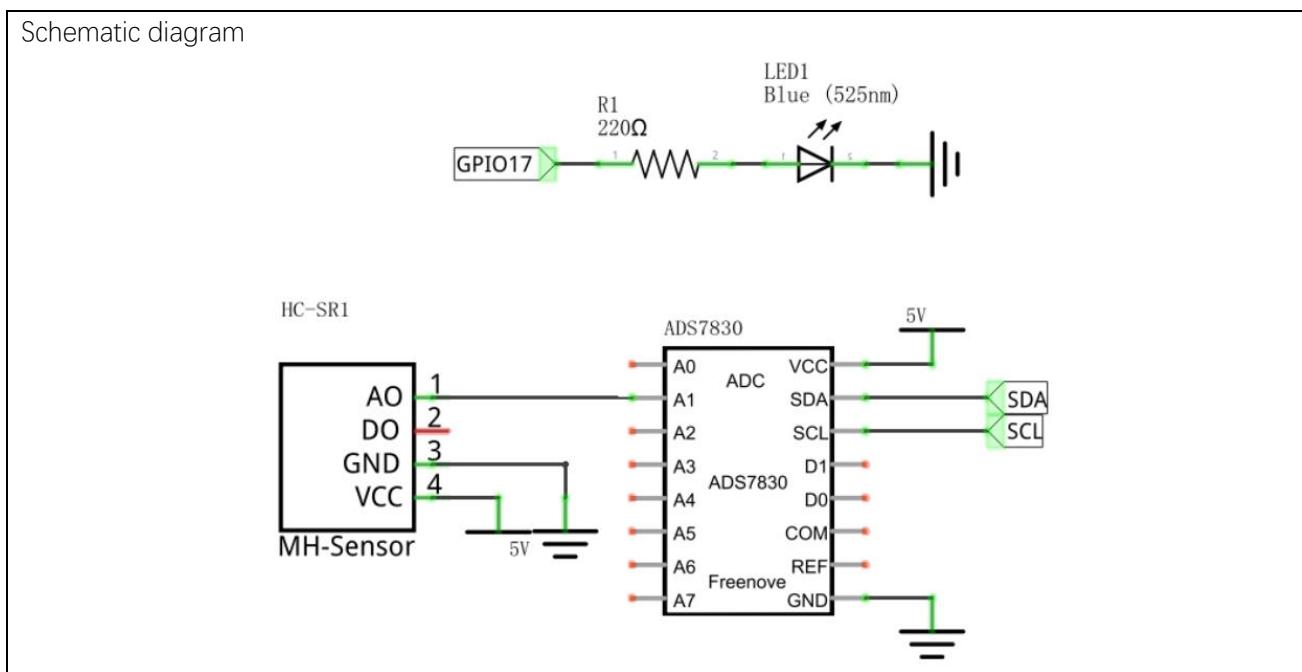
A Photoresistor is very sensitive to the amount of light present. We can take advantage of the characteristic to make a nightlight with the following function. When the ambient light is less (darker environment), the LED will automatically become brighter to compensate and when the ambient light is greater (brighter environment) the LED will automatically dim to compensate.

## Component List

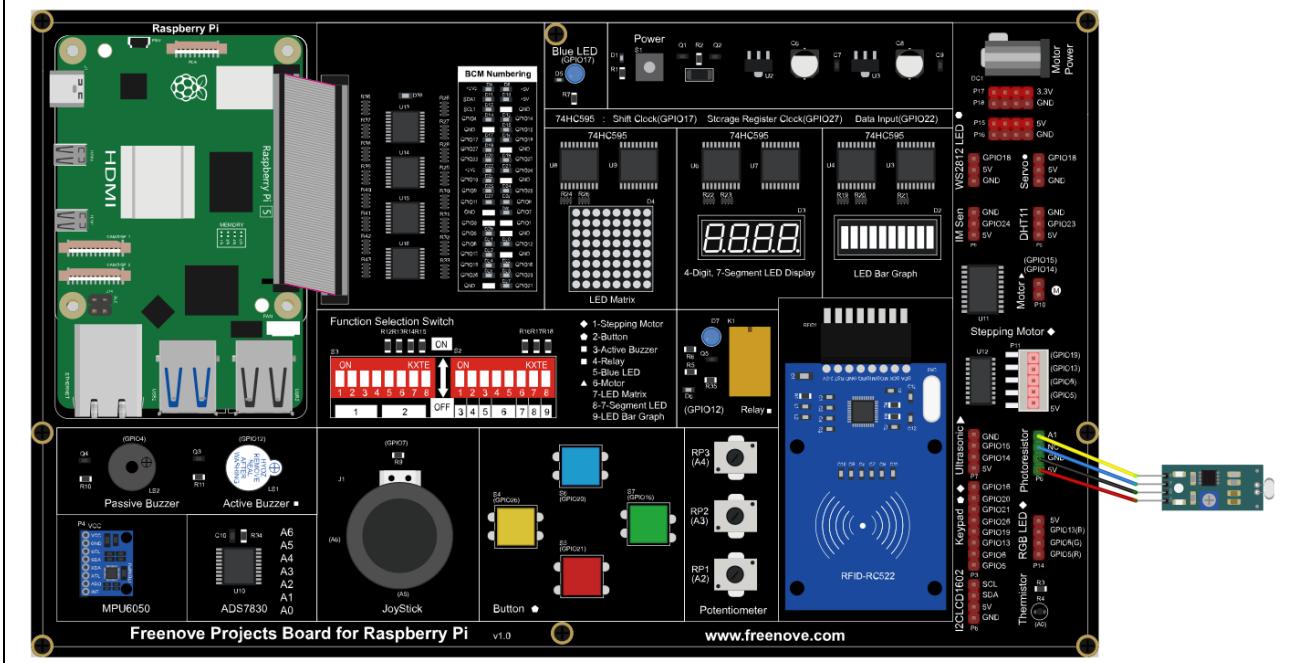




## Circuit



Hardware connection.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In this project, we will change the brightness of the LED based on the light intensity received by the photoresistor.

### Sketch\_08\_Nightlamp

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_08_Nightlamp
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_08_Nightlamp
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_08_Nightlamp $
```

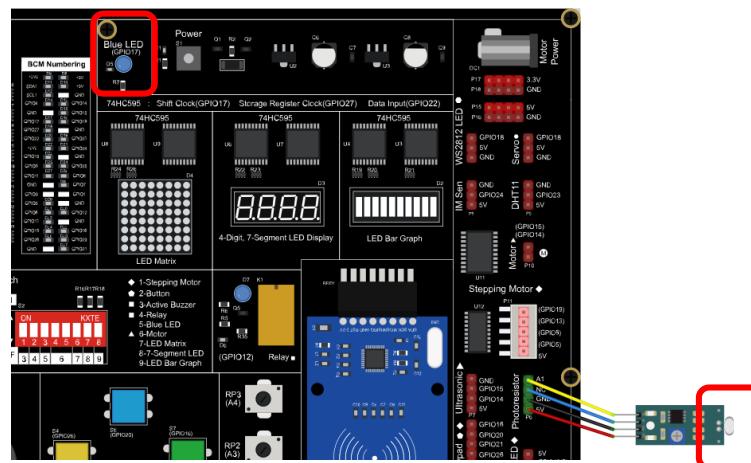
Enter the command to run the code.

```
jbang Nightlamp.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_08_Nightlamp
```

```
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_08_Nightlamp $ jbang Nightlamp.java
```

When the code is running, use light to illuminate the photosensitive module, or cover the photosensitive module with your hand, and you can observe that the brightness of the LED on the board changes accordingly.



support@freenove.com

On the terminal, you can see the ADC and voltage values of the photoresistor are printed.

```
[main] INFO com.pi4j.util.Console - ADC value:186, Voltage:3.65V
[main] INFO com.pi4j.util.Console - ADC value:183, Voltage:3.59V
[main] INFO com.pi4j.util.Console - ADC value:177, Voltage:3.47V
[main] INFO com.pi4j.util.Console - ADC value:168, Voltage:3.29V
```

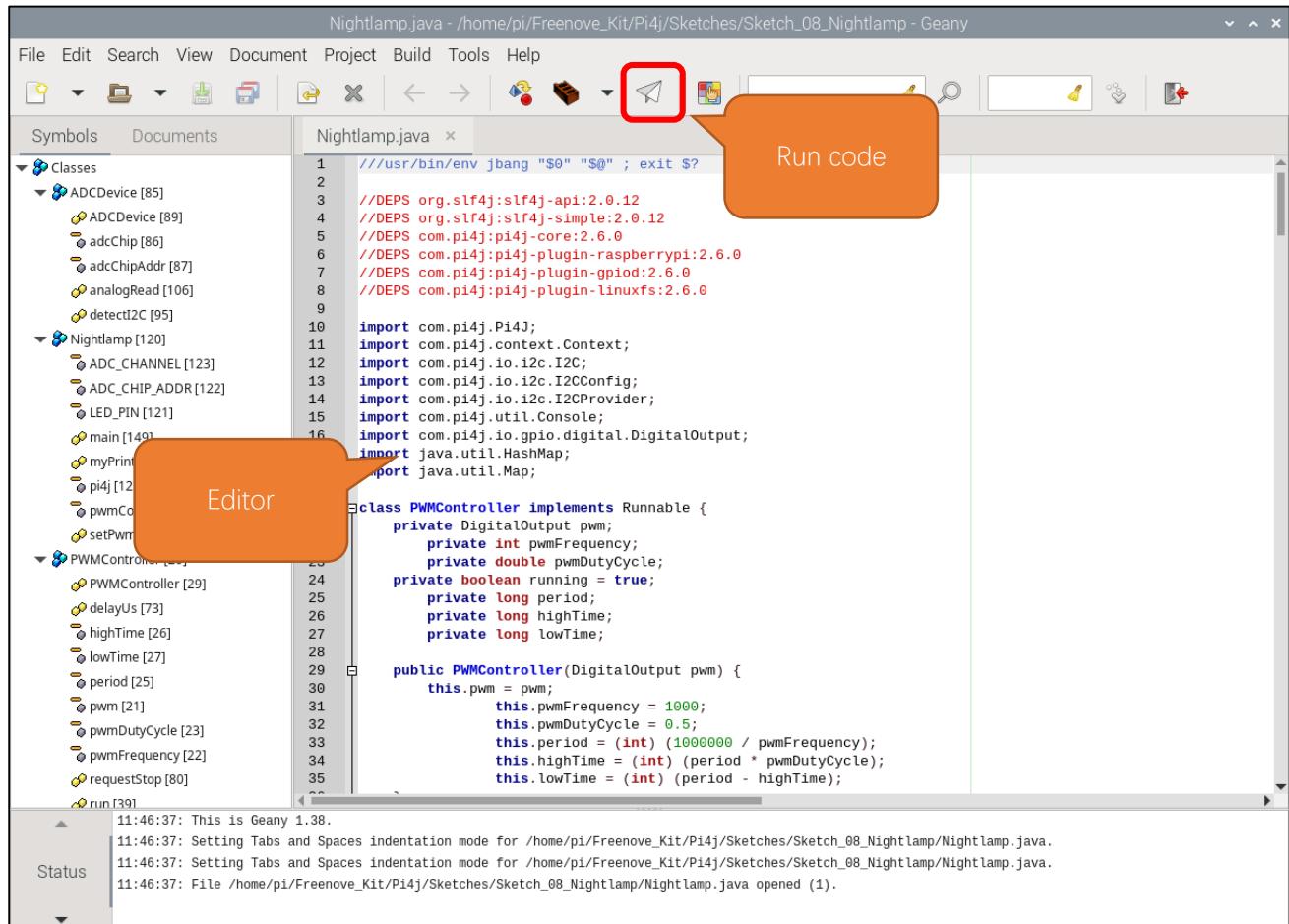
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.util.Console - ADC value:176, Voltage:3.45V
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
```

You can open the code with Geany with the following command to view and edit it.

**geany Nightlamp.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
```

```
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
9
10 import com.pi4j.Pi4J;
11 import com.pi4j.context.Context;
12 import com.pi4j.io.i2c.I2C;
13 import com.pi4j.io.i2c.I2CConfig;
14 import com.pi4j.io.i2c.I2CProvider;
15 import com.pi4j.util.Console;
16 import com.pi4j.io.gpio.digital.DigitalOutput;
17 import java.util.HashMap;
18 import java.util.Map;
19
20 class PWMController implements Runnable {
...
     ....
83 }
84
85 class ADCDevice {
...
     ....
118 }
119
120 public class Nightlamp{
121     private static int LED_PIN = 17;
122     private static int ADC_CHIP_ADDR = 0x48;
123     private static int ADC_CHANNEL = 1;
124
125     private static final Context pi4j = Pi4J.newAutoContext();
126     private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
127
128     public static void setPwmConfig(int pin) throws Exception {
129         DigitalOutput pwm = pi4j.dout().create(pin);
130         PWMController pwmController = new PWMController(pwm);
131         Thread pwmThread = new Thread(pwmController, "PWM Controller " + pin);
132         pwmControllers.put(pin, pwmController);
133         pwmThread.start();
134         Runtime.getRuntime().addShutdownHook(new Thread() -> {
135             pwmController.requestStop();
136             try {
137                 pwmThread.join();
138             } catch (InterruptedException e) {
139                 Thread.currentThread().interrupt();
```

```
140         }
141     }));
142 }
143
144 public static void myPrintln(String format, Object... args) {
145     Console console = new Console();
146     console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
147 }
148
149 public static void main(String[] args) throws Exception {
150     Context pi4j = Pi4J.newAutoContext();
151     I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
152     setPwmConfig(LED_PIN);
153     PWMController led = pwmControllers.get(LED_PIN);
154
155     try {
156         ADCDevice adc = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
157         if (adc.detectI2C()) {
158             while (true) {
159                 int adcValue = adc.analogRead(ADC_CHANNEL);
160                 if (adcValue != -1) {
161                     led.setPwmDutyCycle(((double)adcValue/255.0));
162                     double voltage = (double)adcValue / 255.0 * 5.0;
163                     myPrintln("ADC value:%d, Voltage:%.2fV", adcValue, voltage);
164                 } else {
165                     myPrintln("Failed to read data from ADC.");
166                 }
167                 Thread.sleep(100);
168             }
169         } else {
170             myPrintln("ADS7830 device not detected at address 0x" +
171             Integer.toHexString(ADC_CHIP_ADDR));
172         }
173     } finally {
174         pi4j.shutdown();
175     }
176 }
```

The ADC value at the photosensor is obtained every 100 milliseconds, converted into a PWM duty cycle value for controlling the LED, and then a prompt message is printed on the terminal.

```
while (true) {
    int adcValue = adc.analogRead(ADC_CHANNEL);
    if (adcValue != -1) {
        led.setPwmDutyCycle(((double)adcValue/255.0));
        double voltage = (double)adcValue / 255.0 * 5.0;
        myPrintln("ADC value:%d, Voltage:%.2fV", adcValue, voltage);
    } else {
        myPrintln("Failed to read data from ADC.");
    }
    Thread.sleep(100);
}
```

# Chapter 9 Thermistor

In this chapter, we will learn about Thermistors, which are another kind of Resistor.

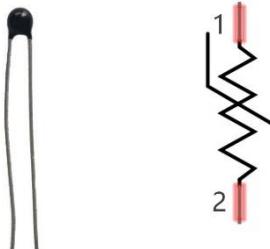
## Project 9.1 Thermometer

A Thermistor is a type of Resistor whose resistance value is dependent on temperature and changes in temperature. Therefore, we can take advantage of this characteristic to make a Thermometer.

### Component knowledge

#### Thermistor

Thermistor is a temperature sensitive resistor. When it senses a change in temperature, the resistance of the Thermistor will change. We can take advantage of this characteristic by using a Thermistor to detect temperature intensity. A Thermistor and its electronic symbol are shown below.



The relationship between resistance value and temperature of a thermistor is:

$$R_t = R \cdot \text{EXP} [B \cdot (1/T_2 - 1/T_1)]$$

Where:

$R_t$  is the thermistor resistance under  $T_2$  temperature;

$R$  is the nominal resistance of thermistor under  $T_1$  temperature;

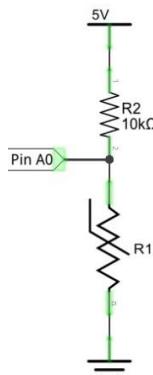
$\text{EXP}[n]$  is nth power of e;

$B$  is for thermal index;

$T_1, T_2$  is Kelvin temperature (absolute temperature). Kelvin temperature = 273.15 + Celsius temperature.

For the parameters of the Thermistor, we use:  $B=3950$ ,  $R=10k$ ,  $T_1=25$ .

The circuit connection method of the Thermistor is similar to photoresistor, as the following:

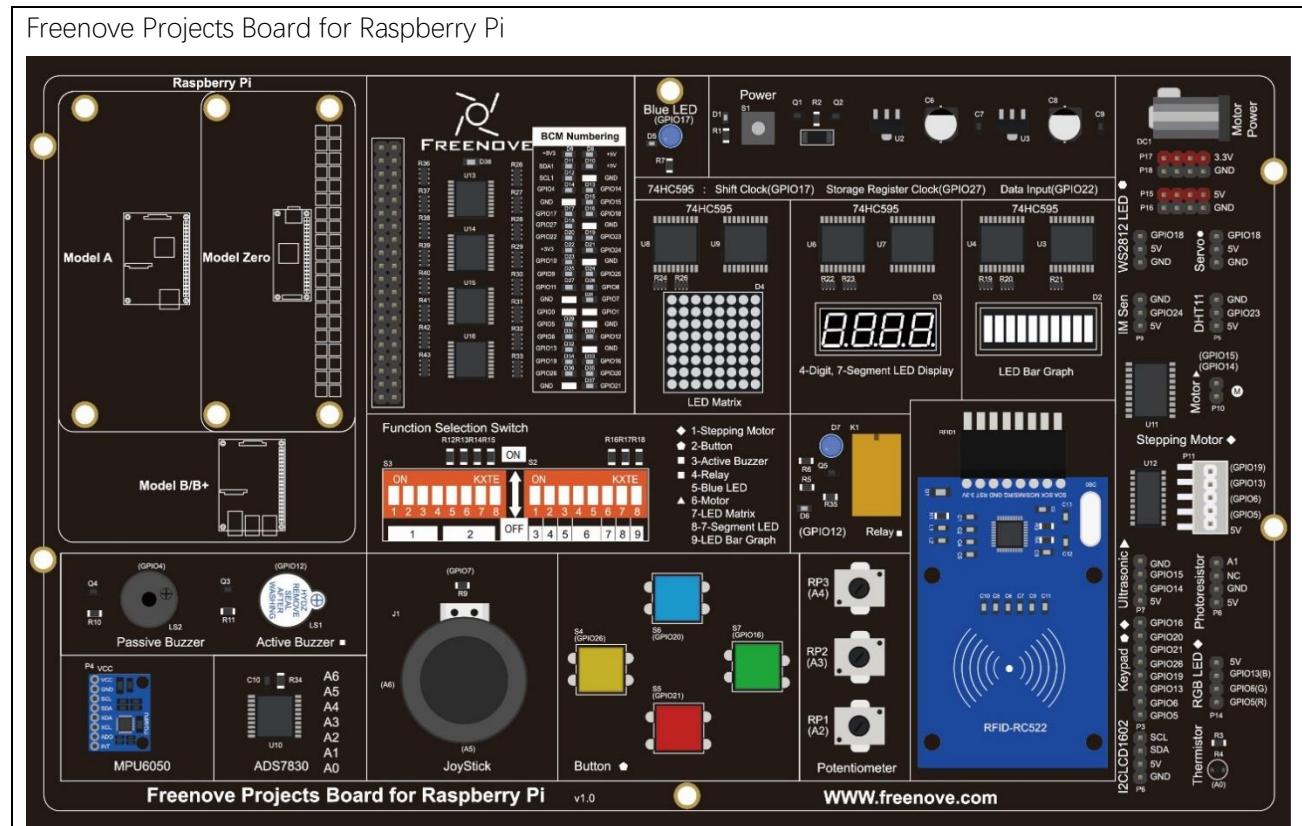


We can use the value measured by the ADC converter to obtain the resistance value of Thermistor, and then we can use the formula to obtain the temperature value.

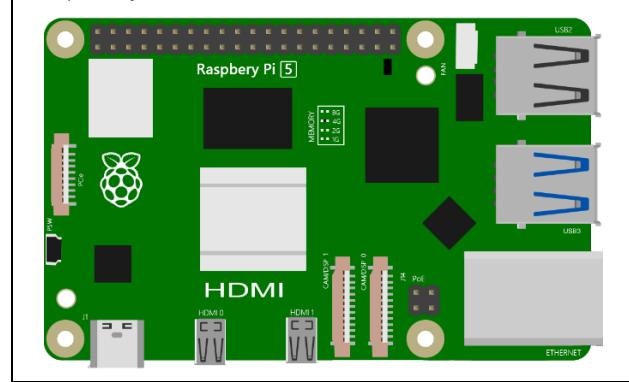
Therefore, the temperature formula can be derived as:

$$T_2 = 1/(1/T_1 + \ln(R_t/R)/B)$$

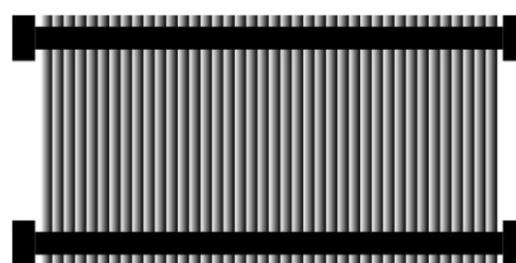
## Component List



Raspberry Pi

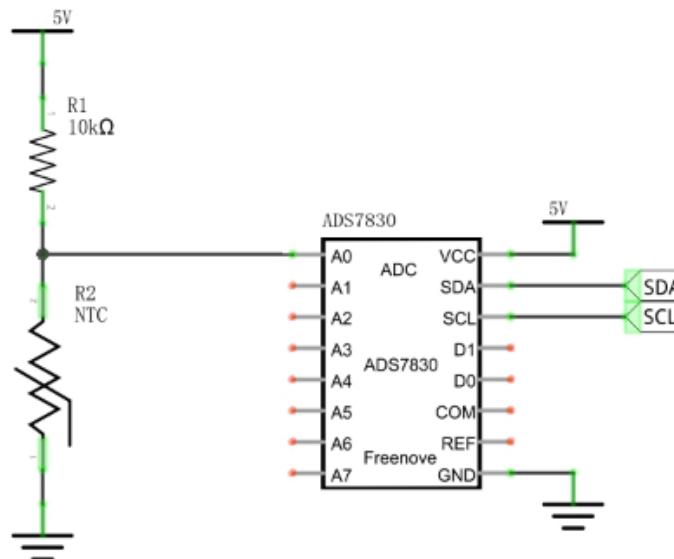


GPIO Ribbon Cable



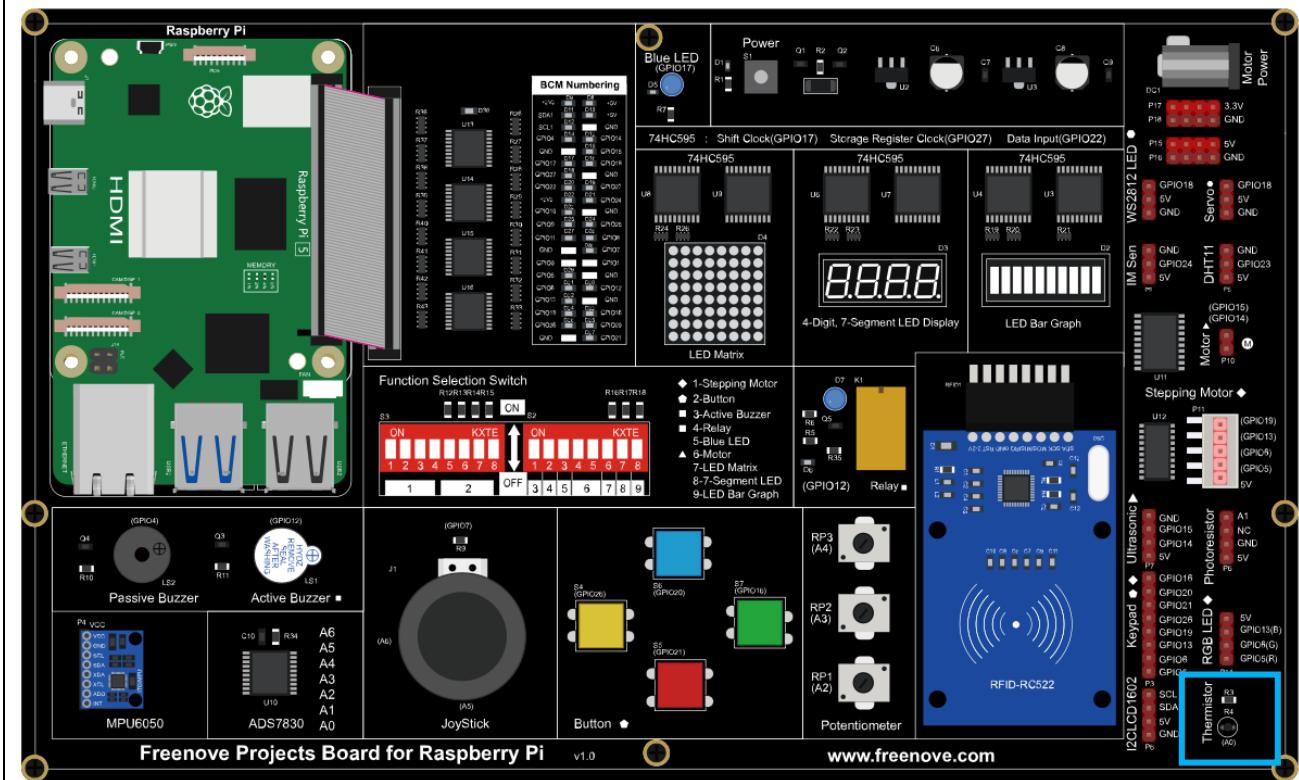
## Circuit

Schematic diagram



Hardware connection.

After running the program, hold your finger against the sensor to observe the change.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

# Sketch

In this project, we will collect the ADC value of the thermistor and calculate its temperature.

## Sketch\_09\_Termometer

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_09_Termometer
```

```
pi@raspberrypi: ~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_09_Thermometer/  
pi@raspberrypi: ~/Freenove_Kit/Pi4j/Sketches/Sketch_09_Thermometer $
```

Enter the command to run the code.

## jbang Thermometer.java

```
pi@raspberrypi:~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_09_Termometer/  
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_09_Termometer $ jbang Thermometer.java
```

After running the code, the Raspberry Pi will obtain the ADC value of the thermistor and convert it into voltage and temperature values, as shown in the figure below.

```
[main] INFO com.pi4j.util.Console - ADC value:117, Voltage:2.29V, Temperature:28.76C  
[main] INFO com.pi4j.util.Console - ADC value:116, Voltage:2.27V, Temperature:29.18C  
[main] INFO com.pi4j.util.Console - ADC value:117, Voltage:2.29V, Temperature:28.76C
```

Press Ctrl+C to exit the program.

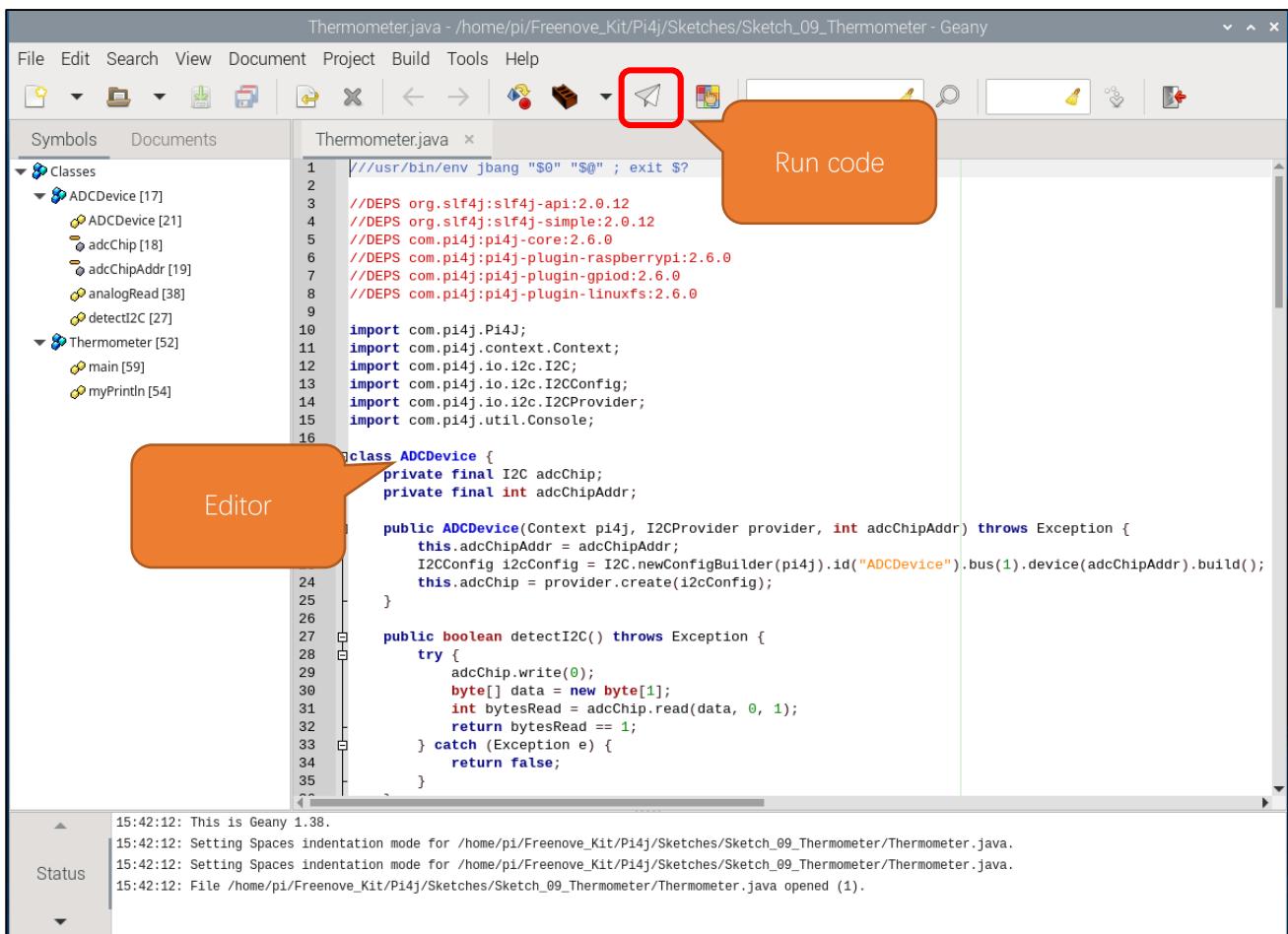
```
pi@raspberrypi: ~/Freenove_Kit/Pi4j/Sketches/Sketch_09_Termometer
File Edit Tabs Help

[main] INFO com.pi4j.util.Console - ADC value:115, Voltage:2.25V, Temperature:29.49C
[main] INFO com.pi4j.util.Console - ADC value:116, Voltage:2.27V, Temperature:29.13C
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[main] INFO com.pi4j.util.Console - ADC value:116, Voltage:2.27V, Temperature:29.13C
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
```

You can open the code with Geany to view and edit it.

## geany Thermometer.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
9
10 import com.pi4j.Pi4J;
11 import com.pi4j.context.Context;
12 import com.pi4j.io.i2c.I2C;
13 import com.pi4j.io.i2c.I2CConfig;
14 import com.pi4j.io.i2c.I2CProvider;
15 import com.pi4j.util.Console;
16
17 class ADCDevice {

```

```
...
}
}

public class Thermometer{
    public static void myPrintln(String format, Object... args) {
        Console console = new Console();
        console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
    }

    public static void main(String[] args) throws Exception {
        Context pi4j = Pi4J.newAutoContext();
        I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
        try {
            int ADC_CHIP_ADDR = 0x48;
            ADCDevice adcDevice = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
            if (adcDevice.detectI2C()) {
                int ADC_CHANNEL = 0;
                while (true) {
                    int adcValue = adcDevice.analogRead(ADC_CHANNEL);
                    if (adcValue != -1) {
                        double voltage = (double)adcValue / 255.0 * 5.0; // calculate voltage
                        double Rt = 10 * voltage / (5.0 - voltage); //calculate
                        resistance value of thermistor
                        double tempK = 1/(1/(273.15 + 25) + Math.log(Rt/10)/3950.0);
                        //calculate temperature (Kelvin)
                        double tempC = tempK -273.15; //calculate temperature (Celsius)
                        myPrintln("ADC value:%d, Voltage:%.2fV, Temperature:%.2fC", adcValue,
                        voltage, tempC);
                    } else {
                        myPrintln("Failed to read data from ADC.");
                    }
                    Thread.sleep(100);
                }
            } else {
                myPrintln("ADS7830 device not detected at address 0x" +
                Integer.toHexString(ADC_CHIP_ADDR));
            }
        } finally {
            pi4j.shutdown();
        }
    }
}
```

Get the ADC value of the thermistor every 100 milliseconds, convert the ADC value into a temperature value according to the formula introduced at [component knowledge](#) section, and print the relevant information on the terminal.

```
int ADC_CHANNEL = 0;
while (true) {
    int adcValue = adcDevice.analogRead(ADC_CHANNEL);
    if (adcValue != -1) {
        double voltage = (double)adcValue / 255.0 * 5.0; // calculate voltage
        double Rt = 10 * voltage / (5.0 - voltage);      //calculate resistance value of
        thermistor
        double tempK = 1/(1/(273.15 + 25) + Math.log(Rt/10)/3950.0); //calculate temperature
        (Kelvin)
        double tempC = tempK -273.15;           //calculate temperature (Celsius)
        myPrintln("ADC value:%d, Voltage:%.2fV, Temperature:%.2fC", adcValue, voltage, tempC);
    } else {
        myPrintln("Failed to read data from ADC.");
    }
    Thread.sleep(100);
}
```

# Chapter 10 Joystick

In an earlier chapter, we learned how to use Rotary Potentiometer. We will now learn about joysticks, which are electronic modules that work on the same principle as the Rotary Potentiometer.

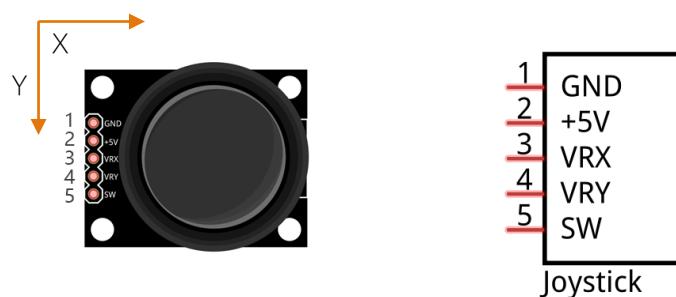
## Project 10.1 Joystick

In this project, we will read the output data of a joystick and display it to the Terminal screen.

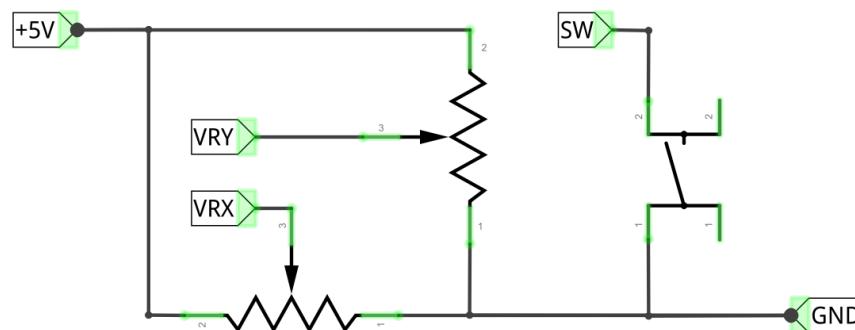
### Component knowledge

#### Joystick

A Joystick is a kind of input sensor used with your fingers. You should be familiar with this concept already as they are widely used in gamepads and remote controls. It can receive input on two axes (Y and or X) at the same time (usually used to control direction on a two dimensional plane). And it also has a third direction capability by pressing down (Z axis/direction).



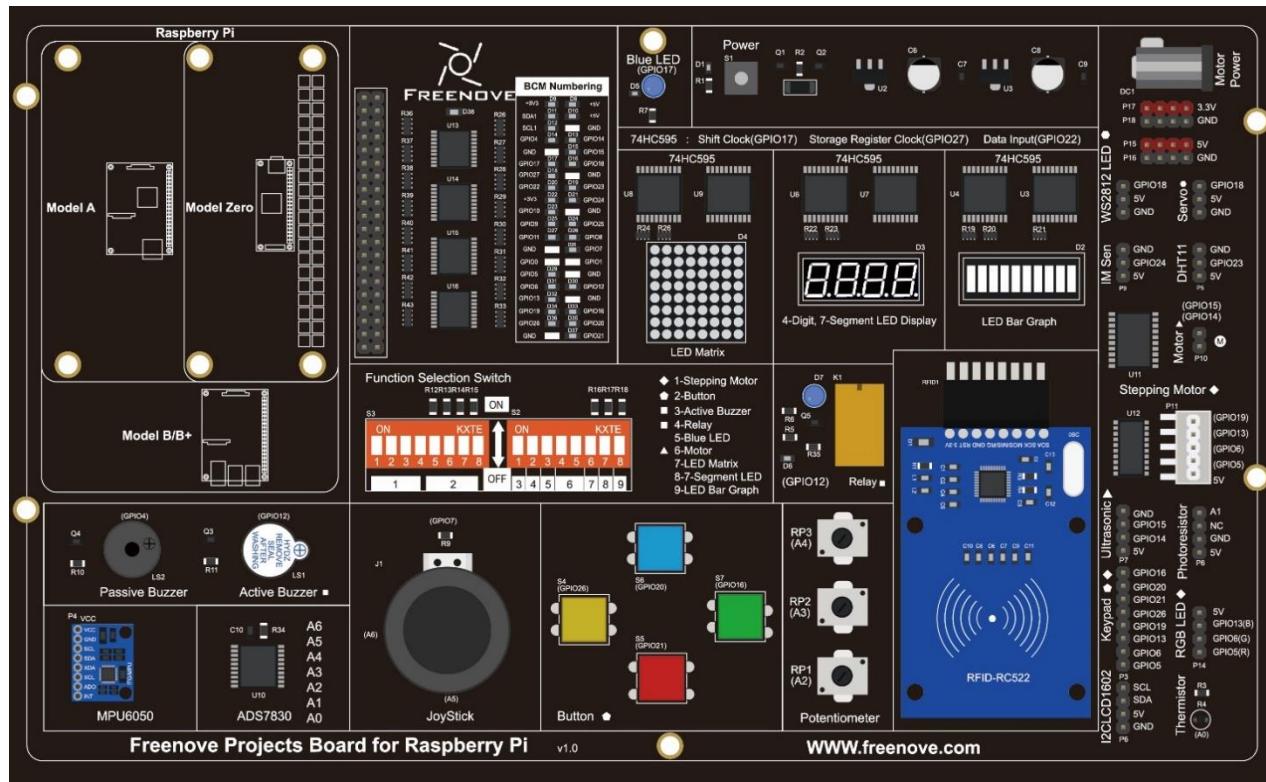
This is accomplished by incorporating two rotary potentiometers inside the Joystick Module at 90 degrees of each other, placed in such a manner as to detect shifts in two directions simultaneously and with a Push Button Switch in the “vertical” axis, which can detect when a User presses on the Joystick.



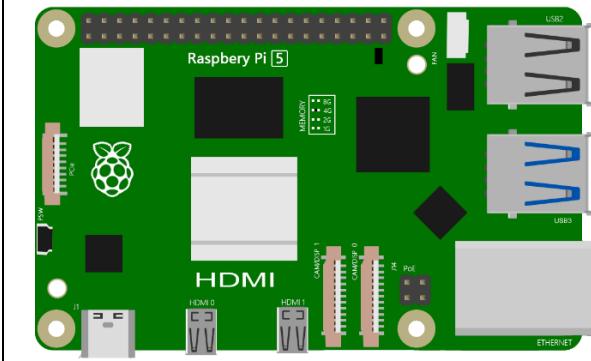
When the Joystick data is read, there are some differences between the axes: data of X and Y axes is analog, which needs to use the ADC. The data of the Z axis is digital, so you can directly use the GPIO to read this data or you have the option to use the ADC to read this.

## Component List

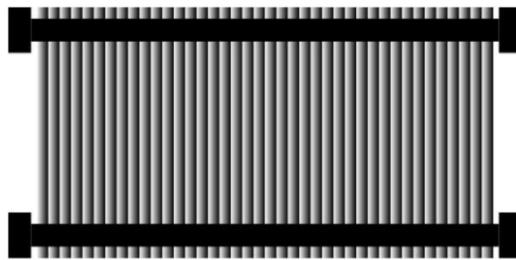
Freenove Projects Board for Raspberry Pi



Raspberry Pi

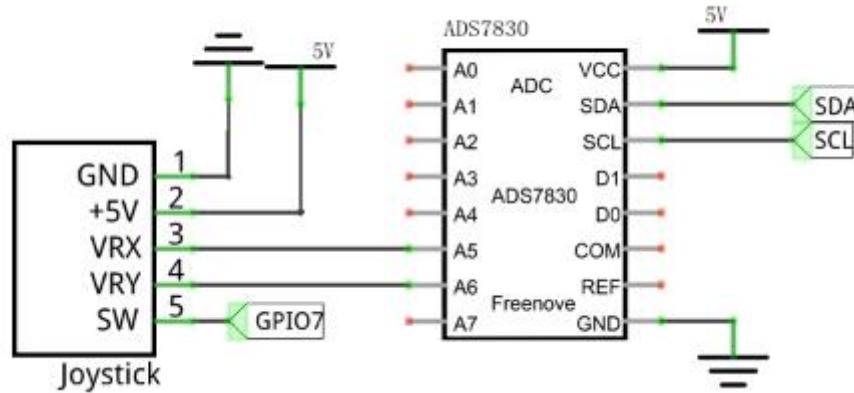


GPIO Ribbon Cable

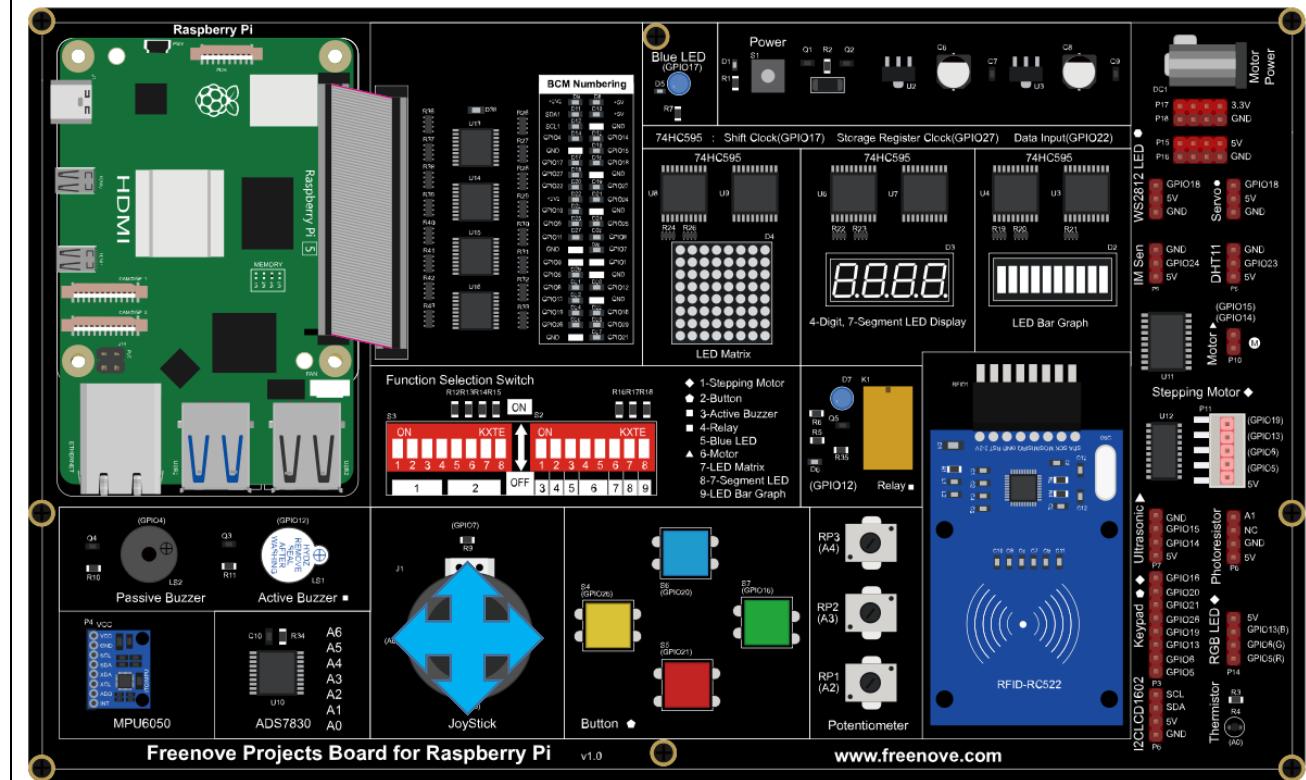


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In this project, we will learn the usage of joystick.

### Sketch\_10\_Joystick

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_10_Joystick
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_10_Joystick
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_10_Joystick $
```

You can enter the command to run the code.

```
jbang Joystick.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_10_Joystick
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_10_Joystick $ jbang Joystick.java
```

After running the code, the Raspberry Pi will obtain the ADC values of the X-axis and Y-axis of the joystick sensor, as well as the value of the Z-axis, and print them out in the terminal.

```
pi@raspberrypi: ~ /Freenove_Kit/Pi4j/Sketches/Sketch_10_Joystick
File Edit Tabs Help
[main] INFO com.pi4j.util.Console - val_X:128, val_Y:121, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:127, val_Y:122, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:128, val_Y:121, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:128, val_Y:121, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:127, val_Y:122, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:128, val_Y:121, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:128, val_Y:122, val_Z:1
```

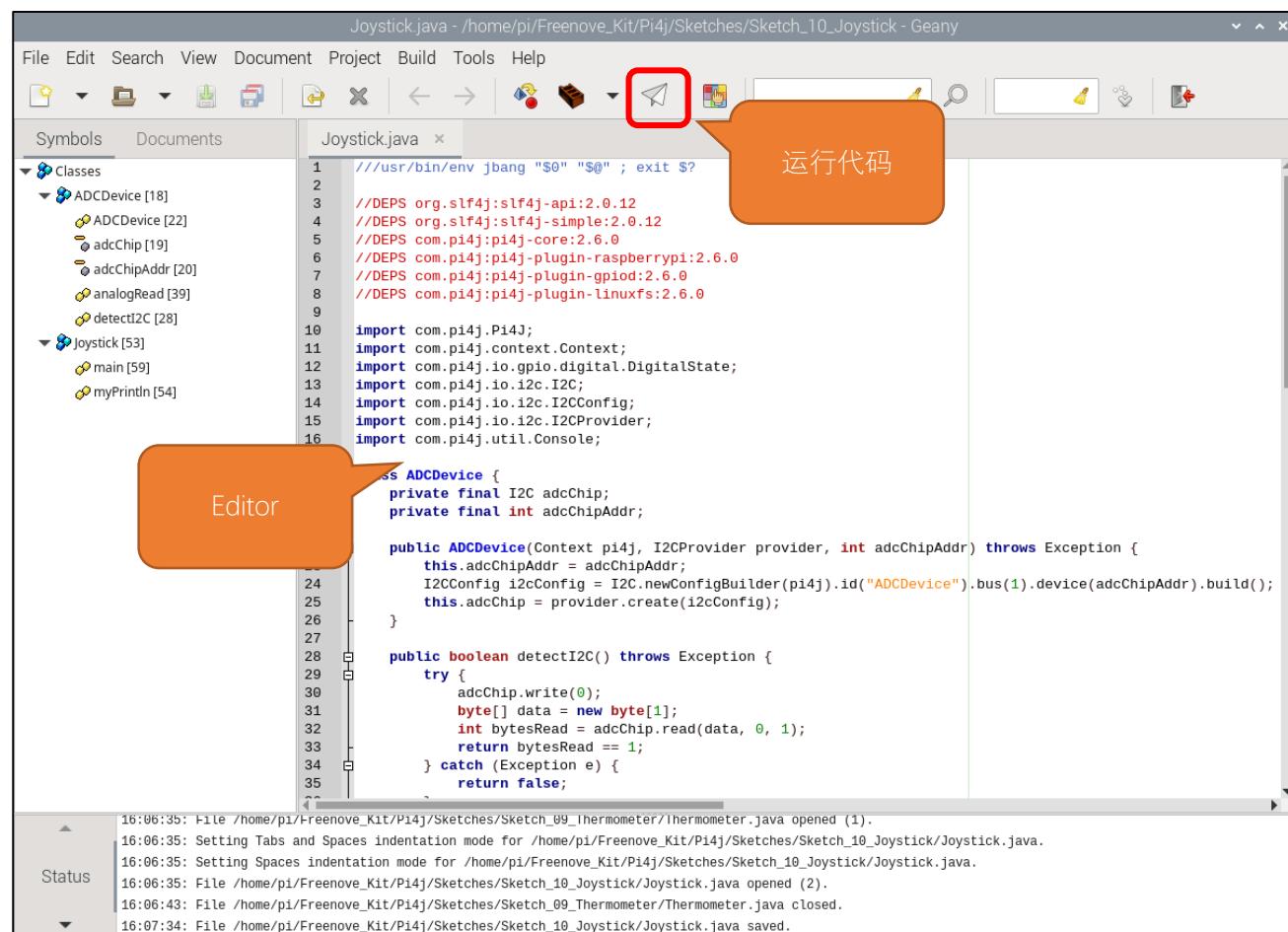
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.util.Console - val_X:128, val_Y:121, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:127, val_Y:121, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:127, val_Y:121, val_Z:1
[main] INFO com.pi4j.util.Console - val_X:128, val_Y:122, val_Z:1
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[main] INFO com.pi4j.util.Console - val_X:128, val_Y:121, val_Z:1
[pi4j-shutdown] INFO com.pi4j.plugin.gpio.provider.gpio.digital.GpioDDigitalInput - Shutdown input listener for DIN-7
[pi4]-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_10_Joystick $
```

You can open the code with Geany to view and edit it.

```
geany Thermometer.java
```

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2 //DEPS org.slf4j:slf4j-api:2.0.12
3 //DEPS org.slf4j:slf4j-simple:2.0.12
4 //DEPS com.pi4j:pi4j-core:2.6.0
5 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
8 import com.pi4j.Pi4J;
9 import com.pi4j.context.Context;
10 import com.pi4j.io.gpio.digital.DigitalState;
11 import com.pi4j.io.i2c.I2C;
12 import com.pi4j.io.i2c.I2CConfig;
13 import com.pi4j.io.i2c.I2CProvider;
14 import com.pi4j.util.Console;
15
16 class ADCDevice {
    .....

```

```
51 }
52
53 public class Joystick{
54     public static void myPrintln(String format, Object... args) {
55         Console console = new Console();
56         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
57     }
58
59     public static void main(String[] args) throws Exception {
60         Context pi4j = Pi4J.newAutoContext();
61         I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
62         final int[] val={0, 0, 1};
63         var button = pi4j.din().create(7);
64         button.addListener(e -> {
65             if (e.state() == DigitalState.LOW) {
66                 val[2] = 0;
67             }
68             else if(e.state() == DigitalState.HIGH) {
69                 val[2] = 1;
70             }
71         });
72         try {
73             int ADC_CHIP_ADDR = 0x48;
74             ADCDevice adc = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
75             if (adc.detectI2C()) {
76                 while (true) {
77                     val[0] = adc.analogRead(5);
78                     val[1] = adc.analogRead(6);
79                     if (val[0] != -1 && val[1] != -1) {
80                         myPrintln("val_X:%d, val_Y:%d, val_Z:%d", val[0], val[1], val[2]);
81                     } else {
82                         myPrintln("Failed to read data from ADC.");
83                     }
84                     Thread.sleep(100);
85                 }
86             } else {
87                 myPrintln("ADS7830 device not detected at address 0x" +
88                         Integer.toHexString(ADC_CHIP_ADDR));
89             }
90         } finally {
91             pi4j.shutdown();
92         }
93     }
94 }
```

Configure the Raspberry Pi's I2C to obtain the ADC values of the x-axis and y-axis of the joystick sensor, and configure the Z-axis to be associated with GPIO7 of the Raspberry Pi.

```
Context pi4j = Pi4J.newAutoContext();
I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
final int[] val={0, 0, 1};
var button = pi4j.din().create(7);
button.addListener(e -> {
    if (e.state() == DigitalState.LOW) {
        val[2] = 0;
    }
    else if(e.state() == DigitalState.HIGH) {
        val[2] = 1;
    }
});
```

The joystick sensor is associated with channel 5 and channel 6 of ADS7830, and its data is acquired every 100 milliseconds and the collected values are printed on the terminal.

```
while (true) {
    val[0] = adc.analogRead(5);
    val[1] = adc.analogRead(6);
    if (val[0] != -1 && val[1] != -1) {
        myPrintln("val_X:%d, val_Y:%d, val_Z:%d", val[0], val[1], val[2]);
    } else {
        myPrintln("Failed to read data from ADC.");
    }
    Thread.sleep(100);
}
```

# Chapter 11 Motor & Driver

In this chapter, we will learn about DC Motors and DC Motor Drivers, and about how to control the speed and direction of a DC Motor.

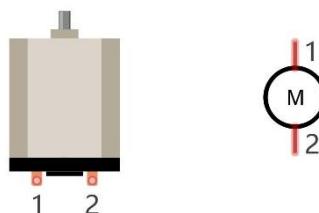
## Project 11.1 Control a DC Motor with a Potentiometer

In this project, a potentiometer will be used to control a DC Motor. When the Potentiometer is at the midpoint position, the DC Motor will STOP, and when the Potentiometer is turned in either direction of this midpoint, the DC Motor speed increases until it reached the endpoint where the DC Motor achieves its maximum speed. When the Potentiometer is turned “Left” of the midpoint, the DC Motor will ROTATE in one direction and when turned “Right” the DC Motor will ROTATE in the opposite direction.

## Component knowledge

### DC Motor

DC Motor is a device that converts electrical energy into mechanical energy. DC Motors consist of two major parts, a Stator and the Rotor. The stationary part of a DC Motor is the Stator and the part that Rotates is the Rotor. The Stator is usually part of the outer case of motor (if it is simply a pair of permanent magnets), and it has terminals to connect to the power if it is made up of electromagnet coils. Most Hobby DC Motors only use Permanent Magnets for the Stator Field. The Rotor is usually the shaft of motor with 3 or more electromagnets connected to a commutator where the brushes (via the terminals 1 & 2 below) supply electrical power, which can drive other mechanical devices. The diagram below shows a small DC Motor with two terminal pins.

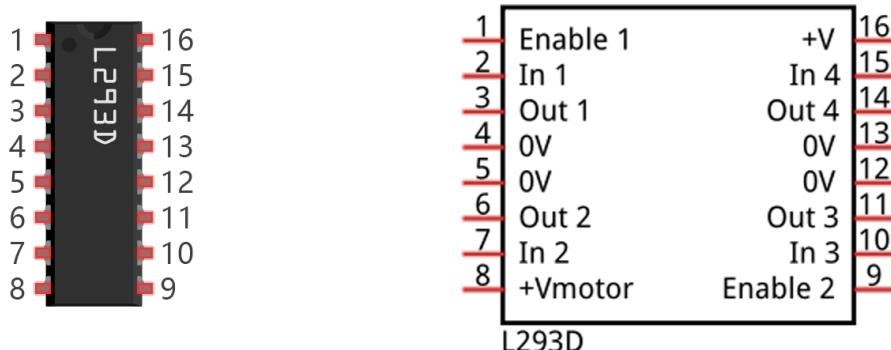


When a DC Motor is connected to a power supply, it will rotate in one direction. If you reverse the polarity of the power supply, the DC Motor will rotate in opposite direction. This is important to note.



## L293D

L293D is an IC Chip (Integrated Circuit Chip) with a 4-channel motor drive. You can drive a Unidirectional DC Motor with 4 ports or a Bi-Directional DC Motor with 2 ports or a Stepper Motor (Stepper Motors are covered later in this Tutorial).



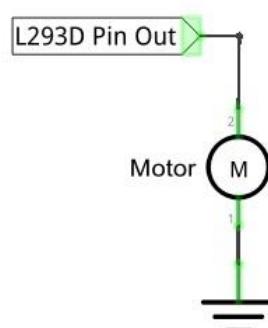
Port description of L293D module is as follows:

Pin name	Pin number	Description
In x	2, 7, 10, 15	Channel x digital signal input pin
Out x	3, 6, 11, 14	Channel x output pin, input high or low level according to In x pin, gets connected to +Vmotor or 0V
Enable1	1	Channel 1 and Channel 2 enable pin, high level enable
Enable2	9	Channel 3 and Channel 4 enable pin, high level enable
0V	4, 5, 12, 13	Power Cathode (GND)
+V	16	Positive Electrode (VCC) of power supply, supply voltage 4.5~36V
+Vmotor	8	Positive Electrode of load power supply, provide power supply for the Out pin x, the supply voltage is +V~36V

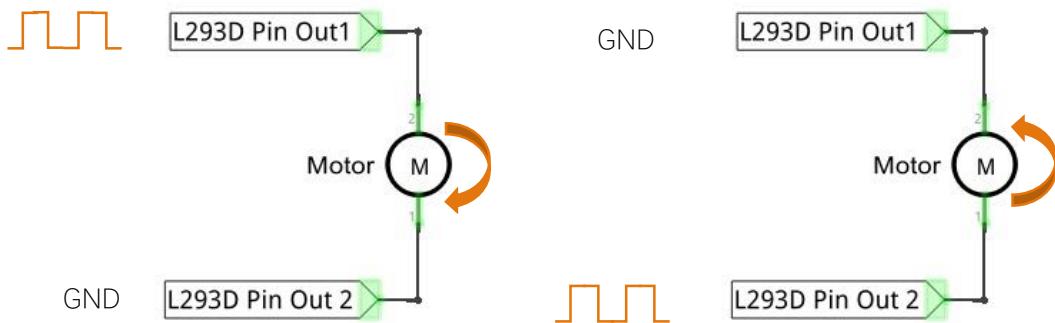
For more details, please see the datasheet for this IC Chip.

When using the L293D to drive a DC Motor, there are usually two connection options.

The following connection option uses one channel of the L293D, which can control motor speed through the PWM. However the motor then can only rotate in one direction.



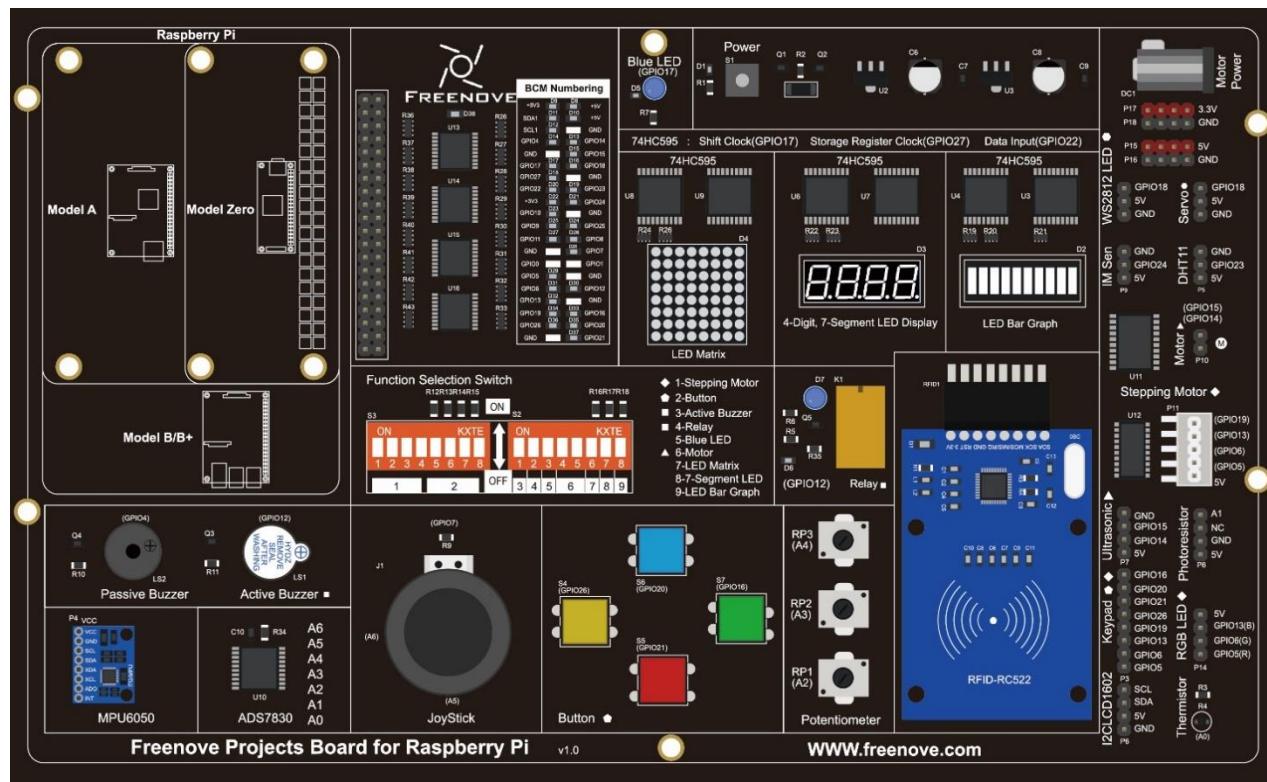
The following connection uses two channels of the L293D: one channel outputs the PWM wave, and the other channel connects to GND. Therefore, you can control the speed of the motor. When these two channel signals are exchanged, it not only controls the speed of motor, but also can control the direction of the motor.



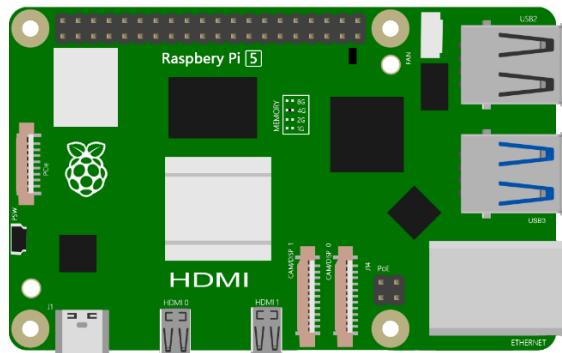
In practical use, the motor is usually connected to channel 1 and by outputting different levels to in1 and in2 to control the rotational direction of the motor, and output to the PWM wave to Enable1 port to control the motor's rotational speed. If the motor is connected to channel 3 and 4 by outputting different levels to in3 and in4 to control the motor's rotation direction, and output to the PWM wave to Enable2 pin to control the motor's rotational speed.

## Component List

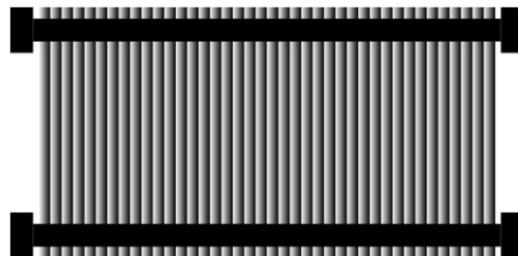
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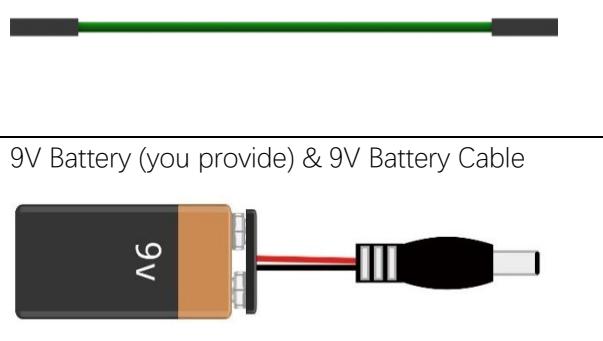
Raspberry Pi



GPIO Ribbon Cable



Jumper Wire



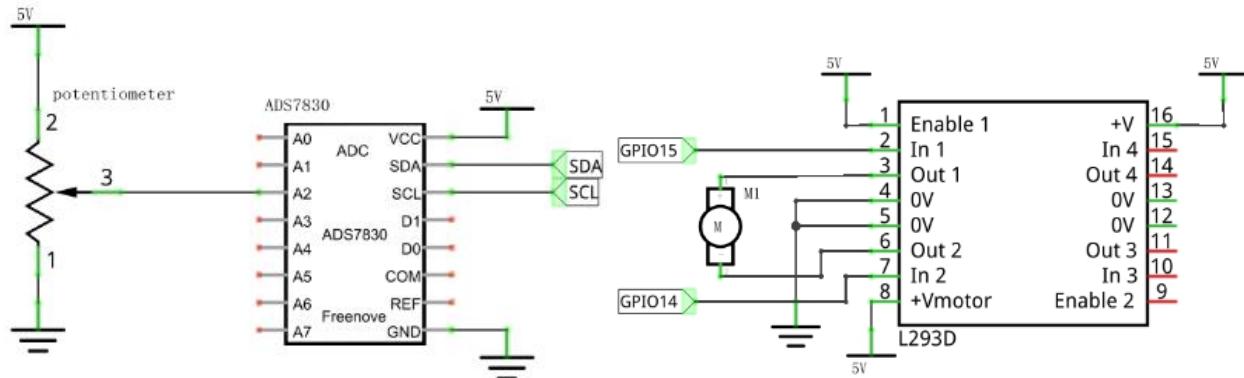
Motor



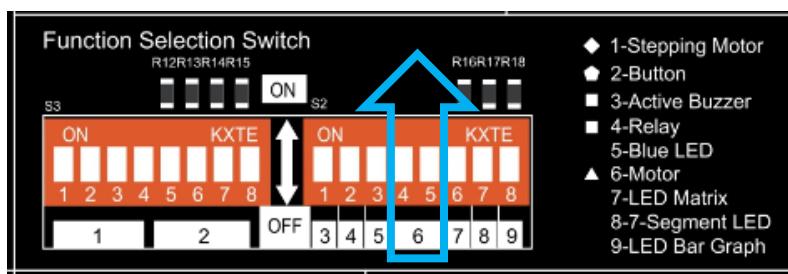
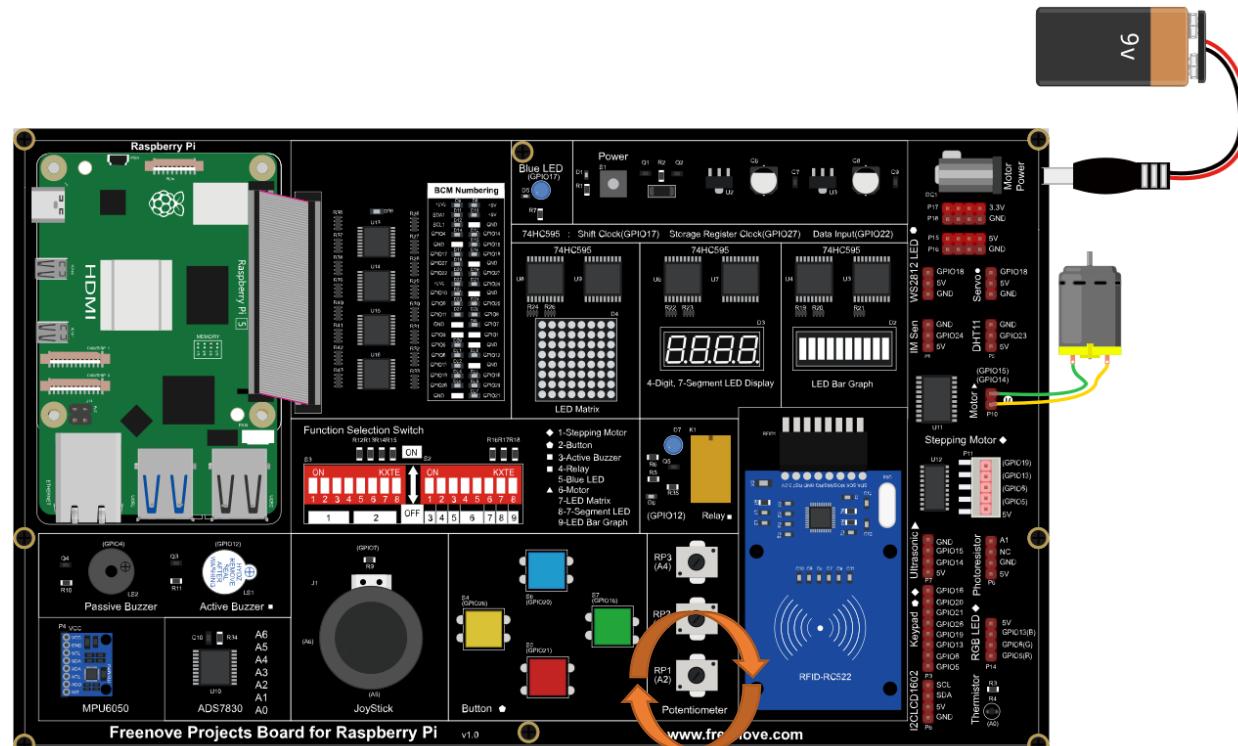
9V Battery (you provide) & 9V Battery Cable

## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In this chapter, we will learn how to use the potentiometer to control the rotation speed and direction of the DC motor.

### Sketch\_11\_Motor

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_11_Motor
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_11_Motor
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_11_Motor $
```

Enter the command to run the code.

```
jbang Motor.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_11_Motor
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_11_Motor $ jbang Motor.java
```

When the code is running, Raspberry Pi will obtain the value of the potentiometer and control the direct of the motor accordingly.

```
[main] INFO com.pi4j.util.Console - ADC value : 129
[main] INFO com.pi4j.util.Console - turn Forward...
[main] INFO com.pi4j.util.Console - The PWM duty cycle is 0%

[main] INFO com.pi4j.util.Console - ADC value : 133
[main] INFO com.pi4j.util.Console - turn Forward...
[main] INFO com.pi4j.util.Console - The PWM duty cycle is 3%

[main] INFO com.pi4j.util.Console - ADC value : 134
[main] INFO com.pi4j.util.Console - turn Forward...
[main] INFO com.pi4j.util.Console - The PWM duty cycle is 4%

[main] INFO com.pi4j.util.Console - ADC value : 133
[main] INFO com.pi4j.util.Console - turn Forward...
[main] INFO com.pi4j.util.Console - The PWM duty cycle is 3%

[main] INFO com.pi4j.util.Console - ADC value : 105
[main] INFO com.pi4j.util.Console - turn Back...
[main] INFO com.pi4j.util.Console - The PWM duty cycle is 18%
```

Press Ctrl+C to exit the code.

```
[main] INFO com.pi4j.util.Console - ADC value : 136
[main] INFO com.pi4j.util.Console - turn Forward...
[main] INFO com.pi4j.util.Console - The PWM duty cycle is 6%

[main] INFO com.pi4j.util.Console - ADC value : 136
[main] INFO com.pi4j.util.Console - turn Forward...
[main] INFO com.pi4j.util.Console - The PWM duty cycle is 6%

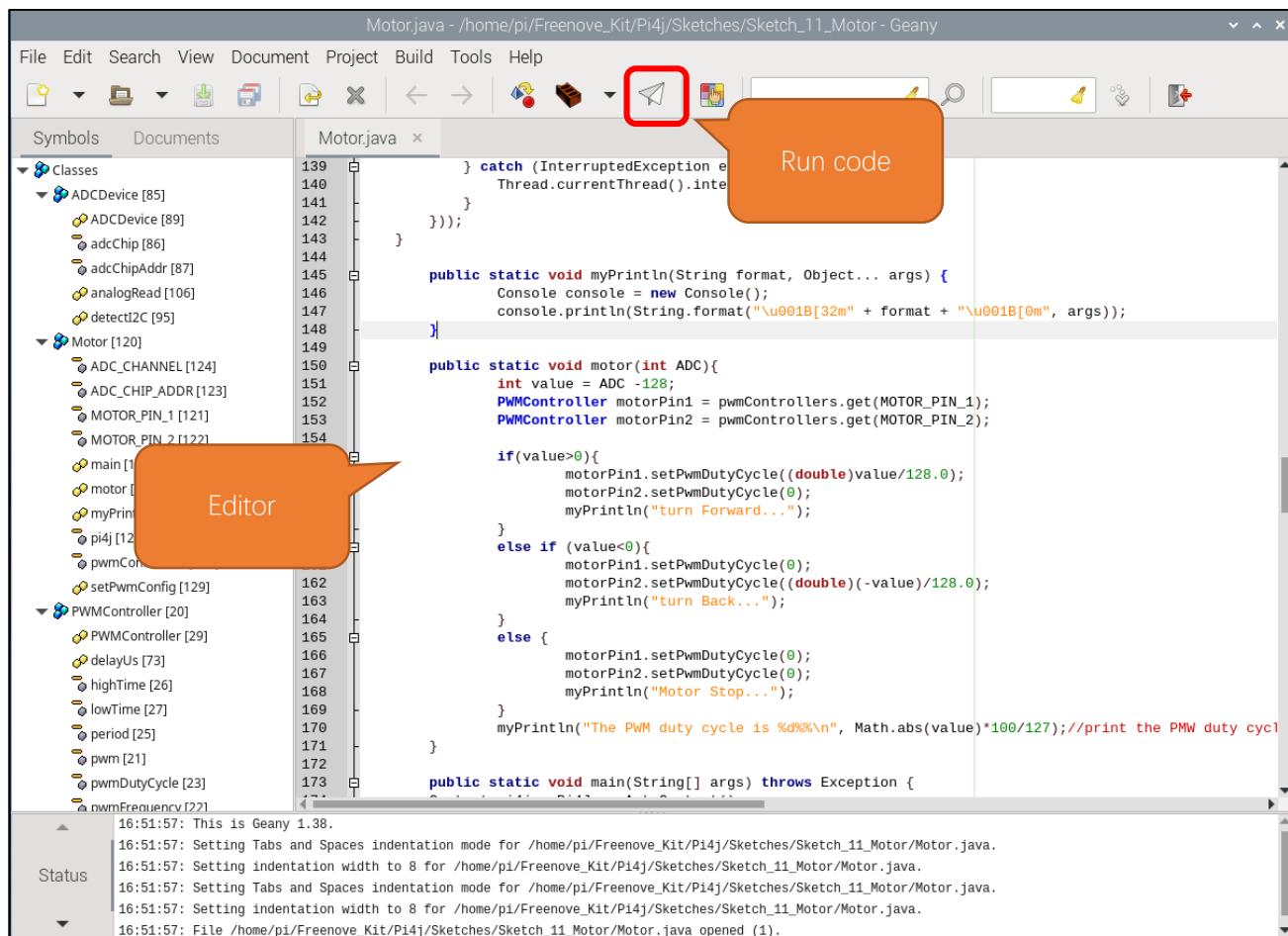
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_11_Motor $
```

You can run the following command to open the code with Geany to view and edit it.

```
geany Motor.java
```



Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //!/usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
9
10 import com.pi4j.Pi4J;
11 import com.pi4j.context.Context;
12 import com.pi4j.io.i2c.I2C;
13 import com.pi4j.io.i2c.I2CConfig;
14 import com.pi4j.io.i2c.I2CProvider;
15 import com.pi4j.util.Console;
16 import com.pi4j.io.gpio.digital.DigitalOutput;
17 ...
18 import java.util.HashMap;

```

```
51 import java.util.Map;
52
53 class PWMController implements Runnable {
54     .....
55 }
56
57 class ADCDevice {
58     .....
59 }
60
61 public class Motor{
62     private static int MOTOR_PIN_1 = 15;
63     private static int MOTOR_PIN_2 = 14;
64     private static int ADC_CHIP_ADDR = 0x48;
65     private static int ADC_CHANNEL = 2;
66     private static final Context pi4j = Pi4J.newAutoContext();
67     private static final Map<Integer, PWMController> pwmControllers = new HashMap<>();
68
69
70     public static void setPwmConfig(int pin) throws Exception {
71         DigitalOutput pwm = pi4j.dout().create(pin);
72         PWMController pwmController = new PWMController(pwm);
73         Thread pwmThread = new Thread(pwmController, "PWM Controller " + pin);
74         pwmControllers.put(pin, pwmController);
75         pwmThread.start();
76
77         Runtime.getRuntime().addShutdownHook(new Thread() -> {
78             pwmController.requestStop();
79             try {
80                 pwmThread.join();
81             } catch (InterruptedException e) {
82                 Thread.currentThread().interrupt();
83             }
84         });
85     }
86
87
88     public static void myPrintln(String format, Object... args) {
89         Console console = new Console();
90         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
91     }
92
93
94     public static void motor(int ADC){
95         int value = ADC -128;
96         PWMController motorPin1 = pwmControllers.get(MOTOR_PIN_1);
97         PWMController motorPin2 = pwmControllers.get(MOTOR_PIN_2);
98     }
99 }
```

```
154     if(value>0) {
155         motorPin1.setPwmDutyCycle((double)value/128.0);
156         motorPin2.setPwmDutyCycle(0);
157         myPrintln("turn Forward... ");
158     }
159     else if (value<0) {
160         motorPin1.setPwmDutyCycle(0);
161         motorPin2.setPwmDutyCycle((double)(-value)/128.0);
162         myPrintln("turn Back... ");
163     }
164     else {
165         motorPin1.setPwmDutyCycle(0);
166         motorPin2.setPwmDutyCycle(0);
167         myPrintln("Motor Stop... ");
168     }
169     myPrintln("The PWM duty cycle is %d%\n", Math.abs(value)*100/127);
170 }
171
172 public static void main(String[] args) throws Exception {
173     Context pi4j = Pi4J.newAutoContext();
174     I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
175     setPwmConfig(MOTOR_PIN_1);
176     setPwmConfig(MOTOR_PIN_2);
177     try {
178         ADCDevice adc = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
179         if (adc.detectI2C()) {
180             while (true) {
181                 int adcValue = adc.analogRead(ADC_CHANNEL);
182                 myPrintln("ADC value : %d", adcValue);
183                 motor(adcValue);
184                 Thread.sleep(100);
185             }
186         } else {
187             myPrintln("ADS7830 device not detected at address 0x" +
188             Integer.toHexString(ADC_CHIP_ADDR));
189         }
190     } finally {
191         pi4j.shutdown();
192     }
193 }
194 }
```

The range of ADC value is 0-255, with 128 as the middle value. If the ADC value is greater than 128, the Raspberry Pi controls the motor to rotate forward. The larger the ADC value, the faster the motor speed. Conversely, if the ADC value is less than 128, the Raspberry Pi controls the motor to rotate backward. The smaller the ADC value, the faster the motor speed.

```
public static void motor(int ADC) {
    int value = ADC - 128;
    PWMController motorPin1 = pwmControllers.get(MOTOR_PIN_1);
    PWMController motorPin2 = pwmControllers.get(MOTOR_PIN_2);

    if(value>0) {
        motorPin1.setPwmDutyCycle((double)value/128.0);
        motorPin2.setPwmDutyCycle(0);
        myPrintln("turn Forward... ");
    }
    else if (value<0) {
        motorPin1.setPwmDutyCycle(0);
        motorPin2.setPwmDutyCycle((double)(-value)/128.0);
        myPrintln("turn Back... ");
    }
    else {
        motorPin1.setPwmDutyCycle(0);
        motorPin2.setPwmDutyCycle(0);
        myPrintln("Motor Stop... ");
    }
    myPrintln("The PWM duty cycle is %d%%\n", Math.abs(value)*100/127);
}
```

The ADC value at the potentiometer is obtained every 100 milliseconds, and the ADC value is sent as a parameter to the motor function to control the direction and speed of the motor, and the ADC value is printed out in the terminal.

```
while (true) {
    int adcValue = adc.analogRead(ADC_CHANNEL);
    myPrintln("ADC value : %d", adcValue);
    motor(adcValue);
    Thread.sleep(100);
}
```



# Chapter 12 Relay & LED

In this chapter, we will learn a kind of special switch module, Relay Module.

## Project 12.1 Relay & LED

### Component knowledge

#### Relay

Relays are a type of Switch that open and close circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing contacts in another circuit using an electromagnet to initiate the Switch action. When the electromagnet is energized (powered), it will attract internal contacts completing a circuit, which act as a Switch. Many times Relays are used to allow a low powered circuit (and a small low amperage switch) to safely turn ON a larger more powerful circuit. They are commonly found in automobiles, especially from the ignition to the starter motor.

The following is a basic diagram of a common Relay and the image and circuit symbol diagram of the 5V relay used in this project:

Diagram	Feature:	Symbol

Pin 5 and pin 6 are internally connected to each other. When the coil pin 3 and pin 4 are connected to a 5V power supply, pin 1 will be disconnected from pins 5 & 6 and pin 2 will be connected to pins 5 & 6. Pin 1 is called Closed End and pin 2 is called the Open End.

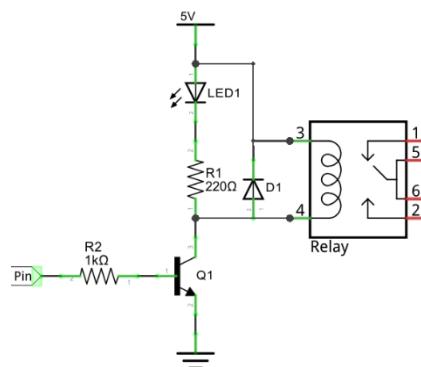
## Inductor

The symbol of Inductance is “L” and the unit of inductance is the “Henry” (H). Here is an example of how this can be encountered:  $1\text{H}=1000\text{mH}$ ,  $1\text{mH}=1000\mu\text{H}$ .

An Inductor is a passive device that stores energy in its Magnetic Field and returns energy to the circuit whenever required. An Inductor is formed by a Cylindrical Core with many Turns of conducting wire (usually copper wire). Inductors will hinder the changing current passing through it. When the current passing through the Inductor increases, it will attempt to hinder the increasing movement of current; and when the current passing through the inductor decreases, it will attempt to hinder the decreasing movement of current. So the current passing through an Inductor is not transient.

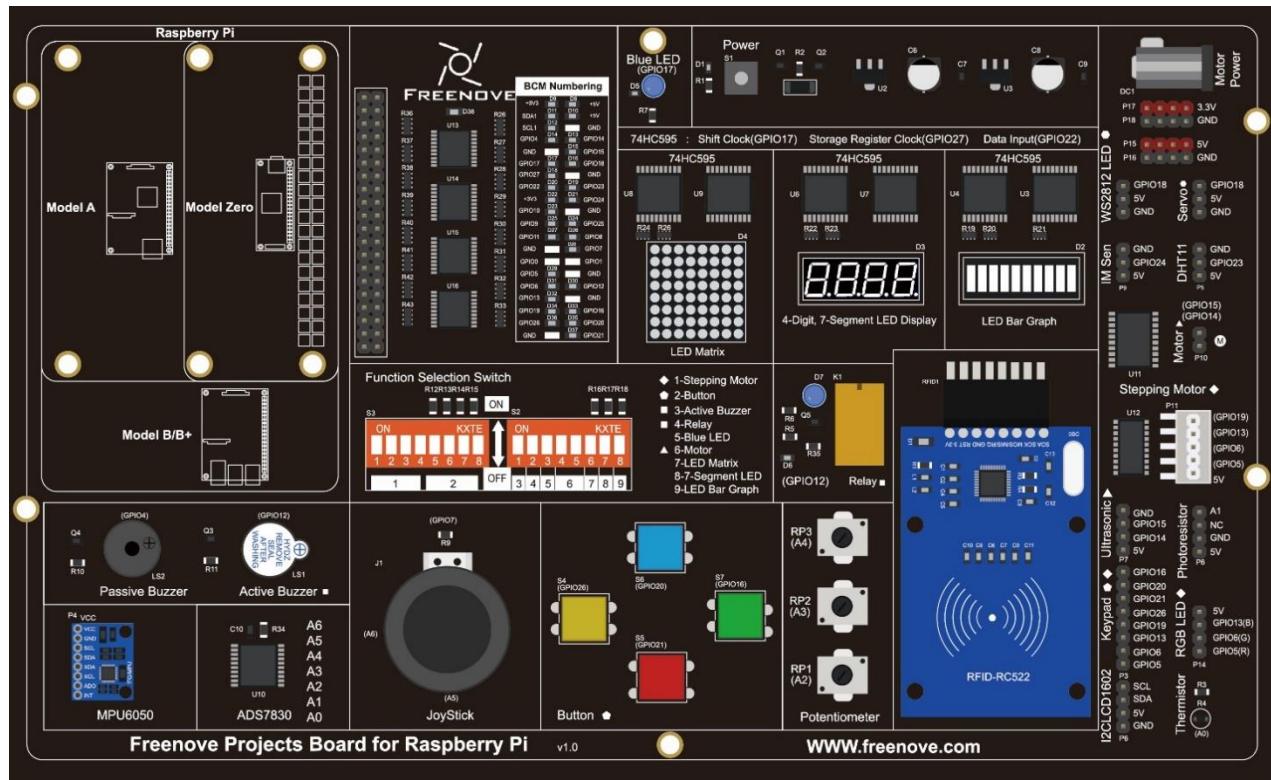


The circuit for a Relay is as follows: The coil of Relay can be equivalent to an Inductor, when a Transistor is present in this coil circuit it can disconnect the power to the relay, the current in the Relay's coil does not stop immediately, which affects the power supply adversely. To remedy this, diodes in parallel are placed on both ends of the Relay coil pins in opposite polar direction. Having the current pass through the diodes will avoid any adverse effect on the power supply.

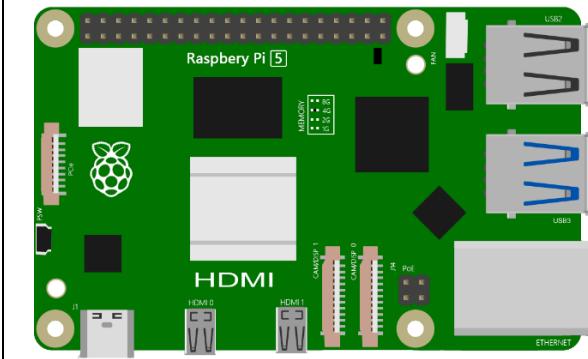


## Component List

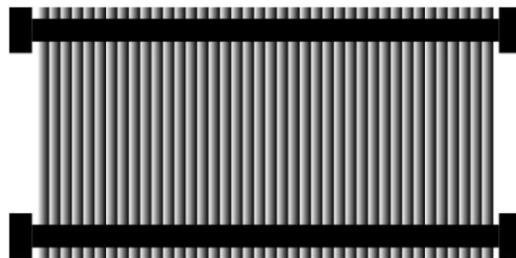
Freenove Projects Board for Raspberry Pi



Raspberry Pi

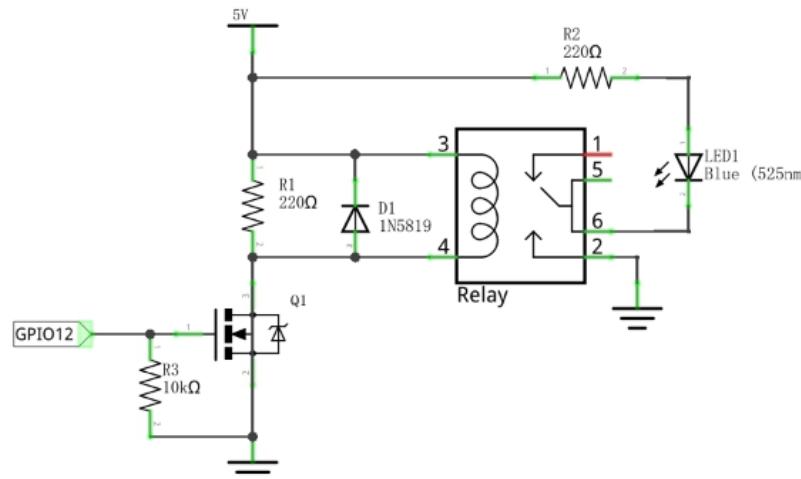


GPIO Ribbon Cable

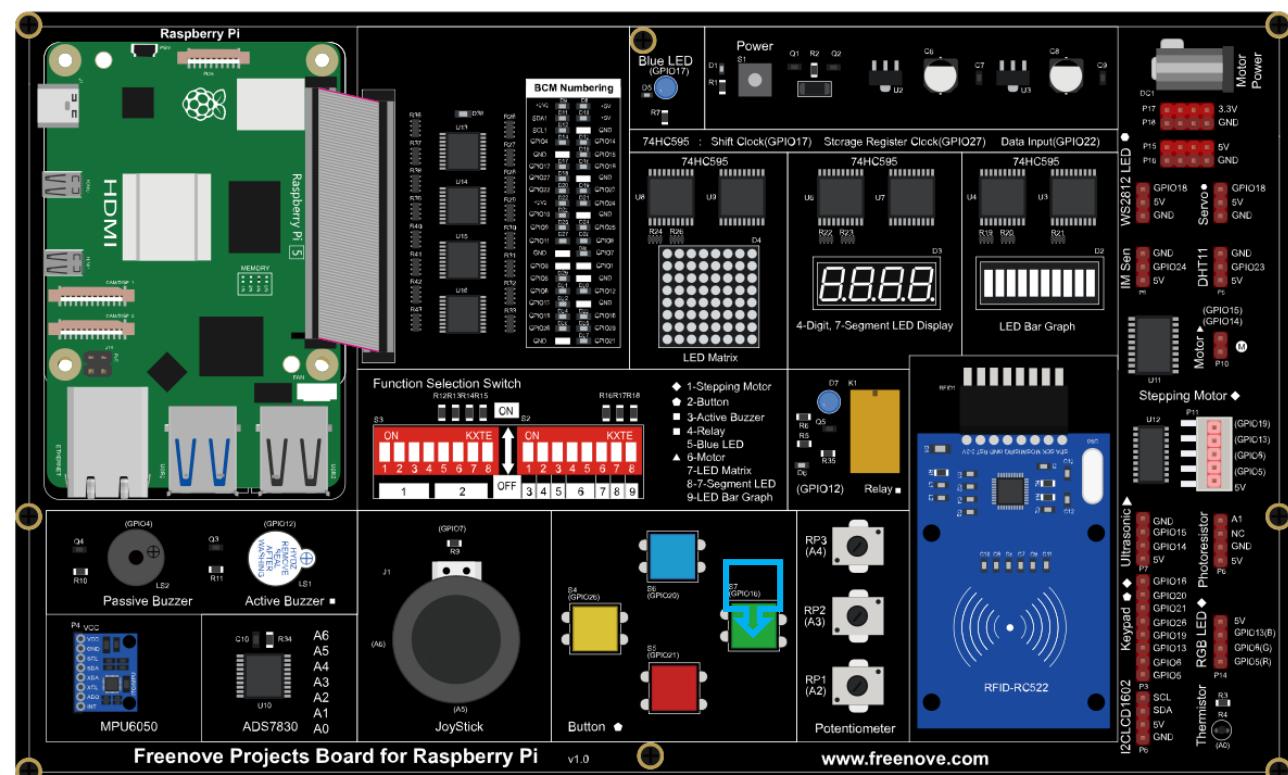


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In the project, we will control the ON and OFF of the relay with the button.

### Sketch\_12\_Relay

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_12_Relay
```

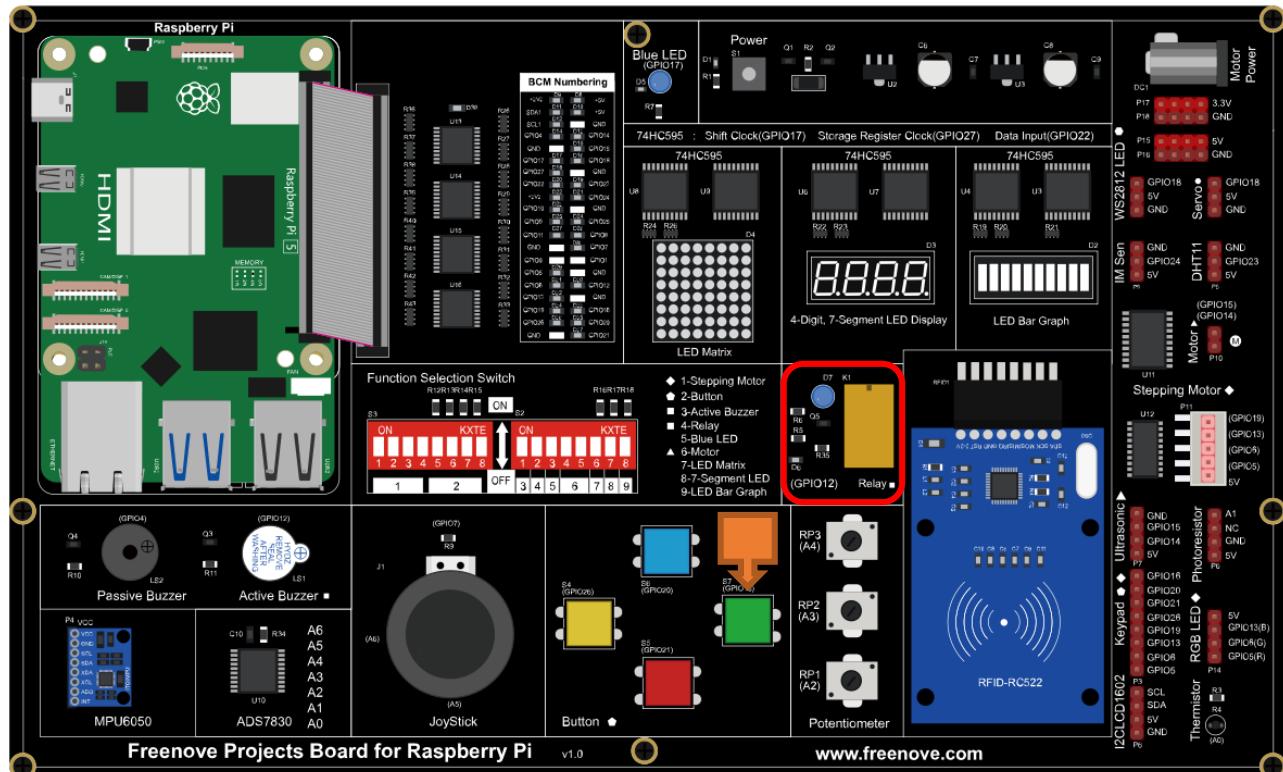
```
pi@raspberrypi:~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_12_Relay/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_12_Relay $
```

Enter the command to run the code.

```
jbang Relay.java
```

```
pi@raspberrypi:~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_12_Relay/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_12_Relay $ jbang Relay.java
```

After running the code, press the button, the relay will be closed and the indicator light will light up. Press the button again, the relay will be disconnected and the indicator light will go out.



Each time when the button is pressed, you can see the messages printed on the terminal.

```
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: true
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: false
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: true
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: false
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: true
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: false
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: true
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: false
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: true
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: false
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: true
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: false
```

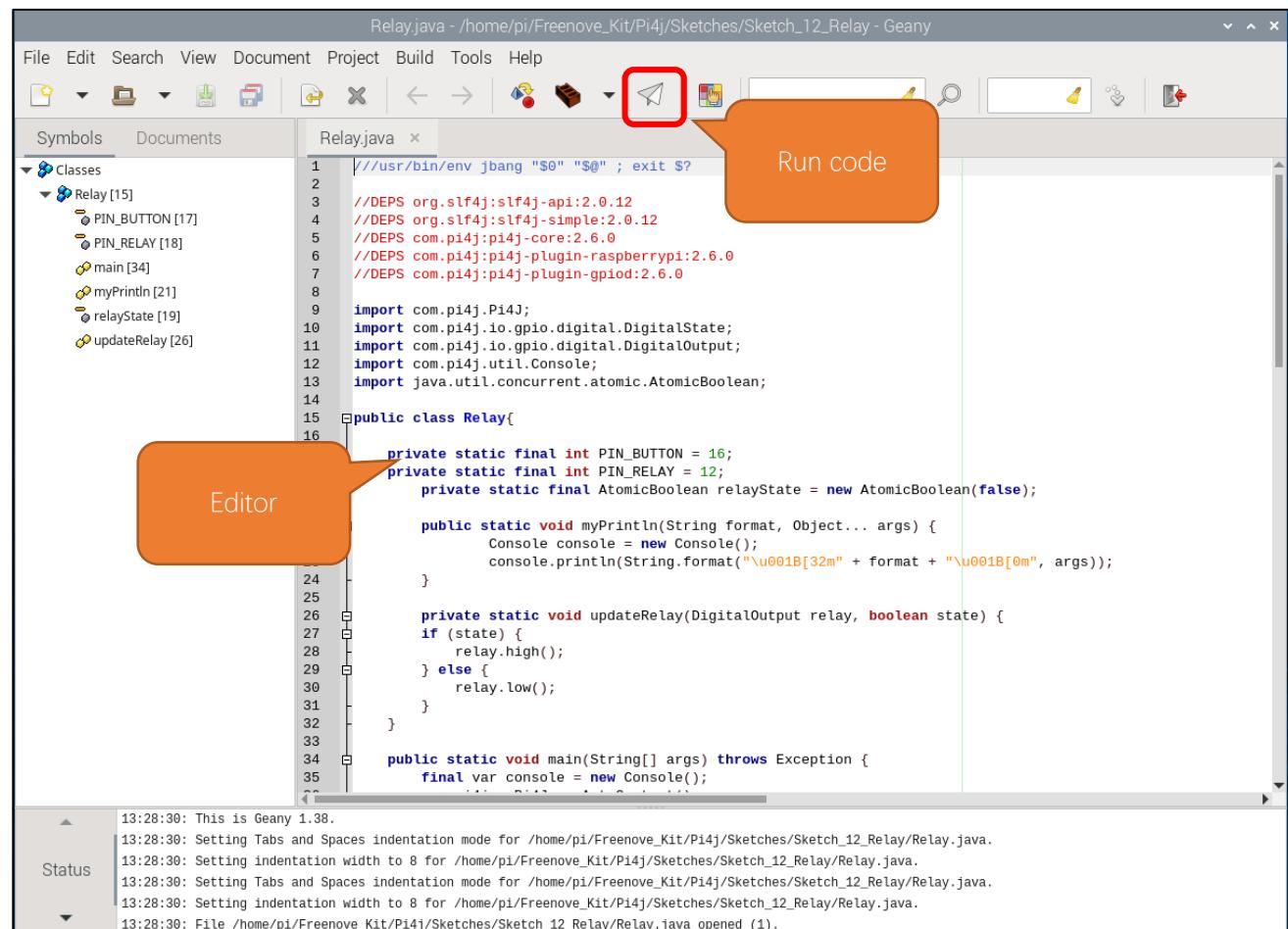
Press Ctrl+C to exit the program.

```
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: false
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: true
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Button was pressed. Relay state: false
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.plugin.gpio.provider.gpio.digital.GpioDDigitalInput - Shutdown input
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_12_Relay $
```

You can run the following command to open the code with Geany to view and edit it.

**geany Relay.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //!/usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.io.gpio.digital.DigitalState;
11 import com.pi4j.io.gpio.digital.DigitalOutput;
12 import com.pi4j.util.Console;
13 import java.util.concurrent.atomic.AtomicBoolean;
14
15 public class Relay{
16     private static final int PIN_BUTTON = 16;
17     private static final int PIN_RELAY = 12;
18     private static final AtomicBoolean relayState = new AtomicBoolean(false);
19
20     public static void myPrintln(String format, Object... args) {
21         Console console = new Console();
22         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
23     }
24
25     private static void updateRelay(DigitalOutput relay, boolean state) {
26         if (state) {
27             relay.high();
28         } else {
29             relay.low();
30         }
31     }
32
33     public static void main(String[] args) throws Exception {
34         final var console = new Console();
35         var pi4j = Pi4J.newAutoContext();
36
37         var relay = pi4j.dout().create(PIN_RELAY);
38         var button = pi4j.din().create(PIN_BUTTON);
39
40         button.addListener(e -> {
41             if (e.state() == DigitalState.LOW) {
42                 relayState.set(!relayState.get());
43                 myPrintln("Button was pressed. Relay state: %s", relayState.get());
44             }
45         });
46     }
47 }
```

```

44         updateRelay(relay, relayState.get());
45     }
46 );
47
48 try{
49     myPrintln("The button gpio is %d, the relay gpio is %d", PIN_BUTTON, PIN_RELAY);
50     while (true) {
51         Thread.sleep(500);
52     }
53 }
54 finally{
55     pi4j.shutdown();
56 }
57 }
58 }
```

Create a boolean variable relayState and set the default state to false.

```
private static final AtomicBoolean relayState = new AtomicBoolean(false);
```

Relay control function: According to the value of the Boolean variable state, the Raspberry Pi controls the GPIO output high and low levels, thereby controlling the relay to be attracted and disconnected.

```
private static void updateRelay(DigitalOutput relay, boolean state) {
    if (state) {
        relay.high();
    } else {
        relay.low();
    }
}
```

Each time a button is pressed, the value of relayState is changed and the value of relayState is sent as a parameter to the relay control function. At the same time, a prompt message is printed in the terminal.

```
button.addListener(e -> {
    if (e.state() == DigitalState.LOW) {
        relayState.set(!relayState.get());
        myPrintln("Button was pressed. Relay state: %s", relayState.get());
        updateRelay(relay, relayState.get());
    }
});
```

# Chapter 13 Servo

Previously, we learned how to control the speed and rotational direction of a DC Motor. In this chapter, we will learn about servos, which are a rotary actuator type motor that can be controlled rotate to specific angles.

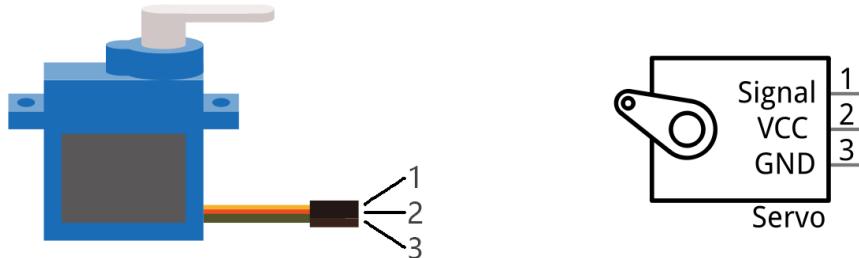
## Project 13.1 Sweep

First, we need to learn how to make a Servo rotate.

### Component knowledge

#### Servo

Servo is a compact package that consists of a DC Motor, a set of reduction gears to provide torque, a sensor and control circuit board. Most Servos only have a 180-degree range of motion via their "horn". Servos can output higher torque than a simple DC Motor alone and they are widely used to control motion in model cars, model airplanes, robots, etc. Servos have three wire leads that usually terminate to a male or female 3-pin plug. Two leads are for electric power: Positive (2-VCC, Red wire), Negative (3-GND, Brown wire), and the signal line (1-Signal, Orange wire) as represented in the Servo provided in your Kit.



We will use a 50Hz PWM signal with a duty cycle in a certain range to drive the Servo. The lasting time 0.5ms-2.5ms of PWM single cycle high level corresponds to the Servo angle 0 degrees - 180 degree linearly. Part of the corresponding values are as follows:

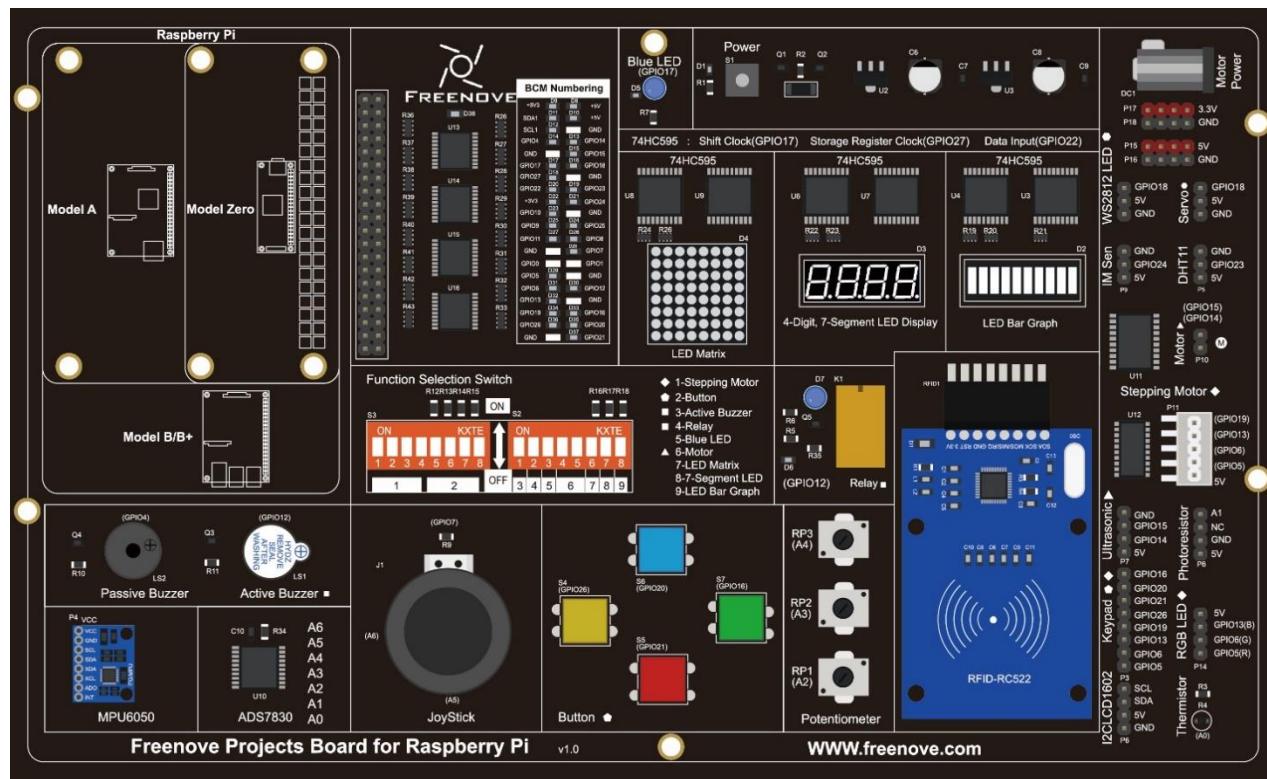
Note: the lasting time of high level corresponding to the servo angle is absolute instead of accumulating. For example, the high-level time lasting for 0.5ms correspond to the 0 degree of the servo. If the high-level time lasts for another 1ms, the servo rotates to 45 degrees.

High level time	Servo angle
0.5ms	0 degree
1ms	45 degree
1.5ms	90 degree
2ms	135 degree
2.5ms	180 degree

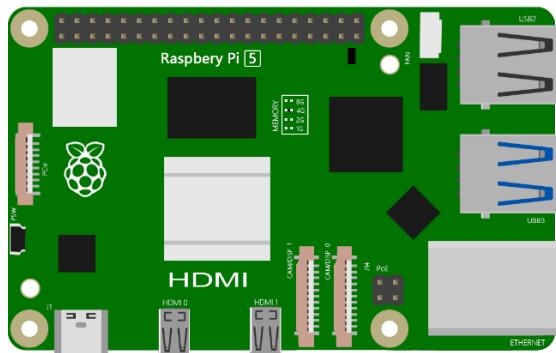
When you change the Servo signal value, the Servo will rotate to the designated angle.

## Component List

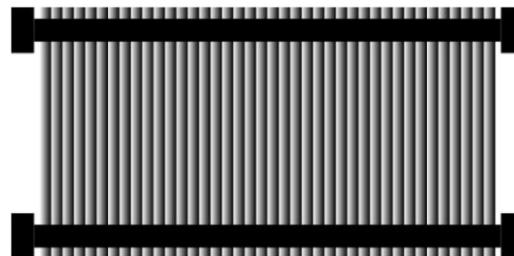
Freenove Projects Board for Raspberry Pi



Raspberry Pi



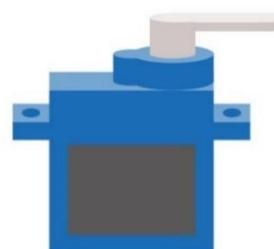
GPIO Ribbon Cable



Jumper Wire

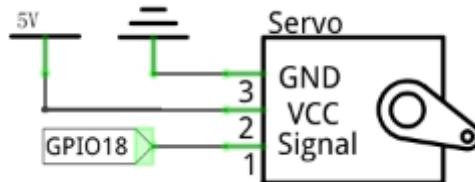


Servo

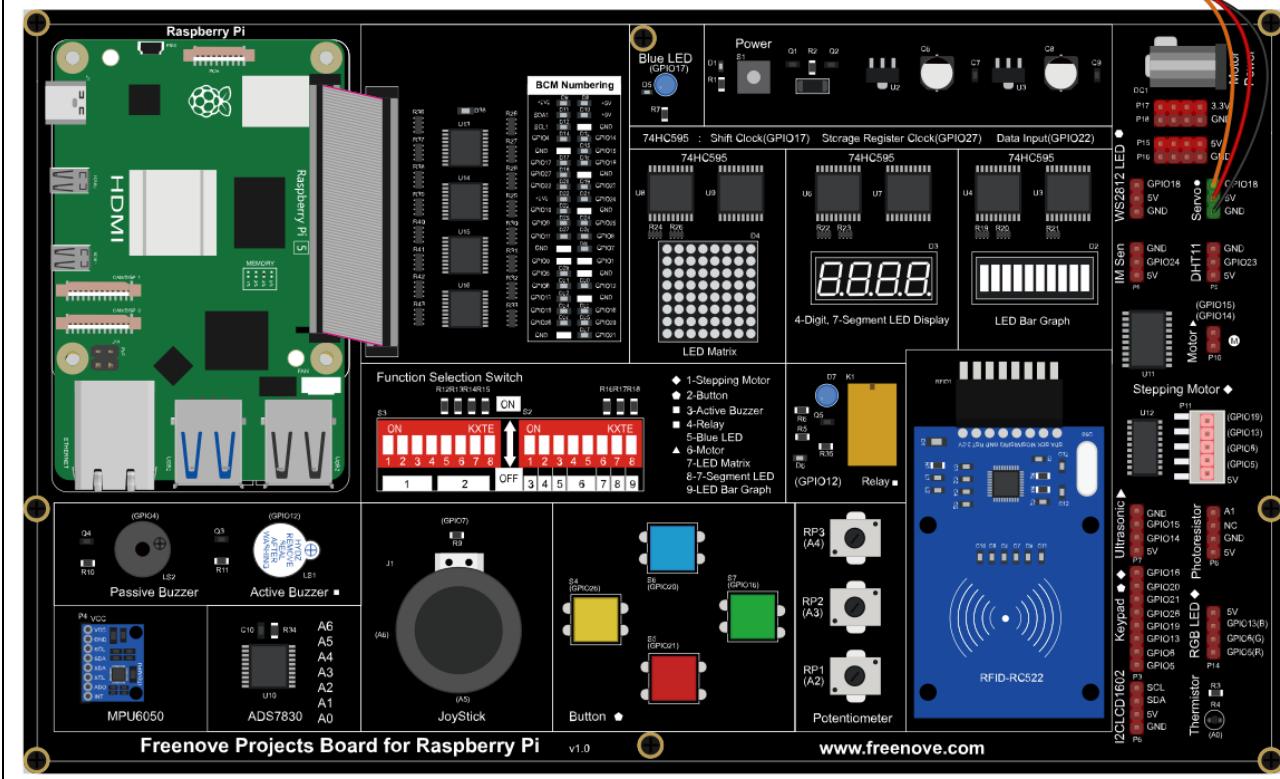
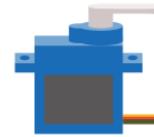


# Circuit

## Schematic diagram



## Hardware connection.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In this chapter, we will learn how to control the servo to rotate at the range of 0 to 180 degrees.

### Sketch\_13\_1\_Sweep

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_13_1_Sweep
```

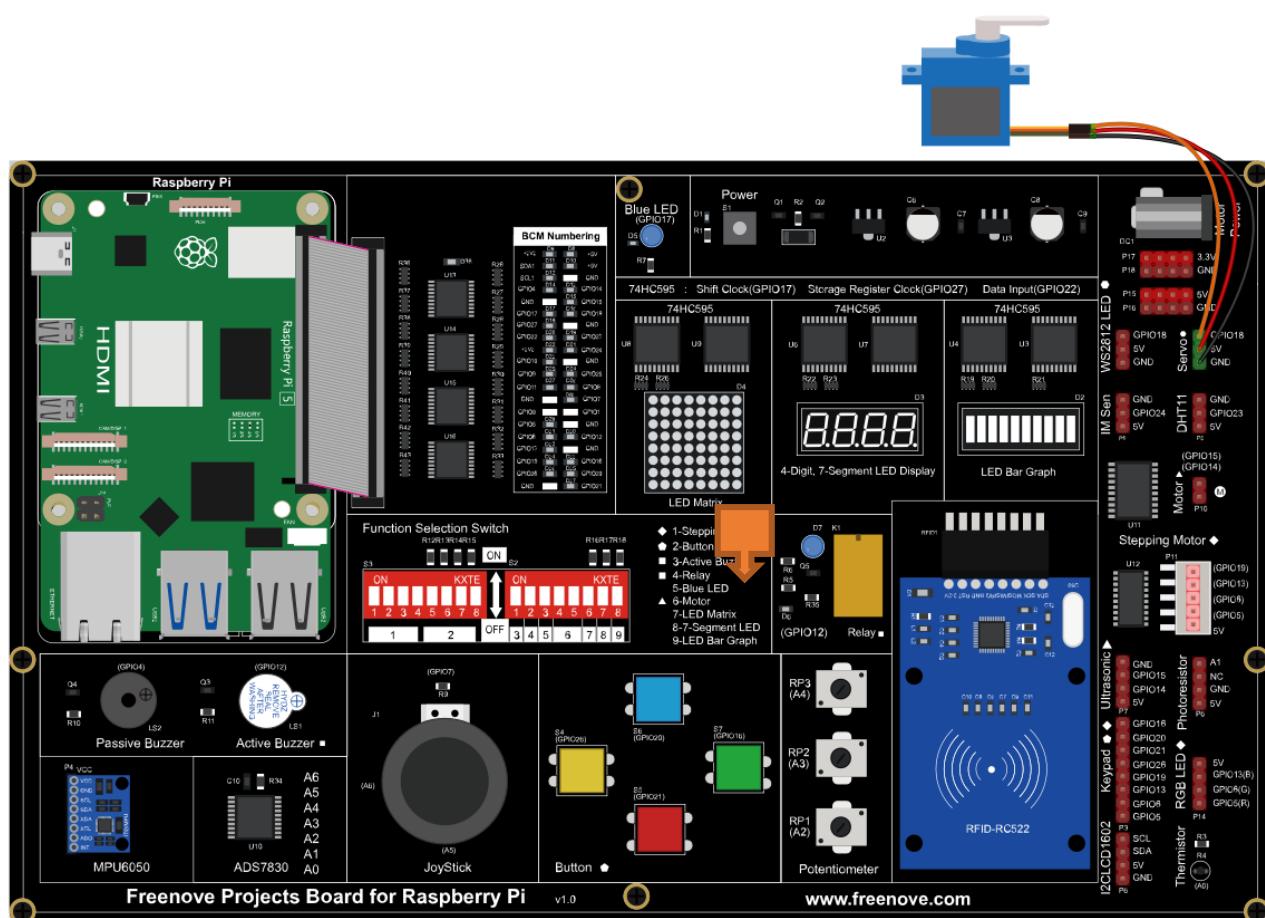
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_13_1_Sweep
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_13_1_Sweep $
```

Enter the command to run the code.

```
jbang Sweep.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_13_1_Sweep
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_13_1_Sweep $ jbang Sweep.java
```

When the code is running, you can see the servo rotate between 0 to 180 degrees.



Meanwhile, the messages are printed on the terminal.

```
[main] INFO com.pi4j.util.Console - The Angle is 30
[main] INFO com.pi4j.util.Console - The Angle is 31
[main] INFO com.pi4j.util.Console - The Angle is 32
[main] INFO com.pi4j.util.Console - The Angle is 33
[main] INFO com.pi4j.util.Console - The Angle is 34
[main] INFO com.pi4j.util.Console - The Angle is 35
[main] INFO com.pi4j.util.Console - The Angle is 36
[main] INFO com.pi4j.util.Console - The Angle is 37
```



Press Ctrl+C to exit the code.

```

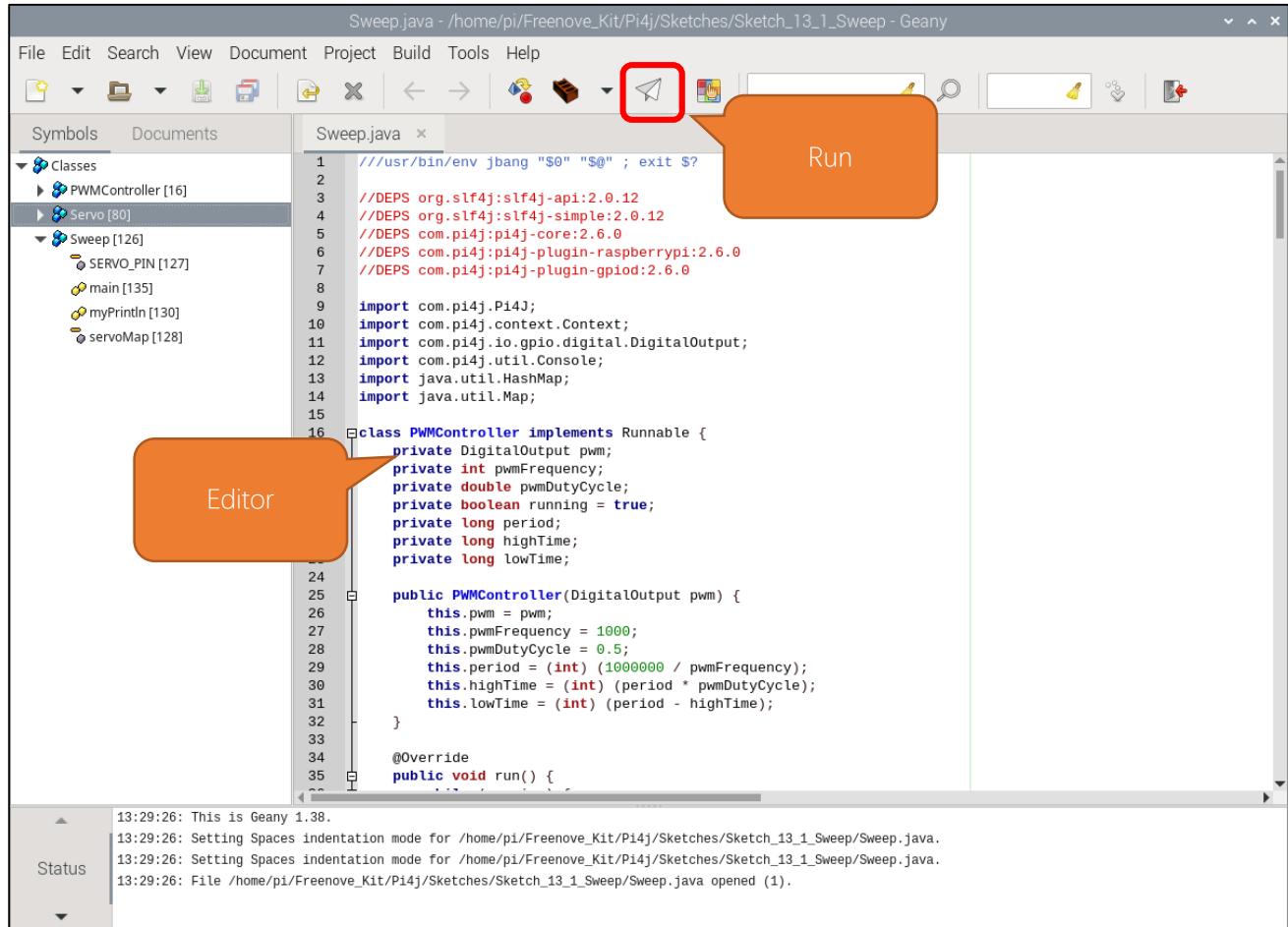
^C[main] INFO com.pi4j.util.Console - The Angle is 133
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[main] INFO com.pi4j.util.Console - The Angle is 132
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_13_1_Sweep $ 

```

You can run the following command to open the code with Geany to view and edit it.

**geany Sweep.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //!/usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.gpio.digital.DigitalOutput;
12 import com.pi4j.util.Console;
13 import java.util.HashMap;
14 import java.util.Map;
15
16 class PWMController implements Runnable {
17     .....
18 }
19
20 class Servo {
21     private final int pin;
22     private final PWMController pwmController;
23     private final Context pi4j;
24
25     public Servo(int pin) throws Exception {
26         this.pin = pin;
27         this.pi4j = Pi4J.newAutoContext();
28         DigitalOutput pwm = pi4j.dout().create(pin);
29         this.pwmController = new PWMController(pwm);
30         Thread pwmThread = new Thread(pwmController, "PWM for Servo on PIN " + pin);
31         pwmThread.start();
32
33         Runtime.getRuntime().addShutdownHook(new Thread(() -> {
34             pwmController.requestStop();
35             try {
36                 pwmThread.join();
37             } catch (InterruptedException e) {
38                 Thread.currentThread().interrupt();
39             }
40         }));
41     }
42
43     public void setFrequency(int frequency) {
```

```
44     pwmController.setPwmFrequency(frequency);
45 }
46
47 public void setDutyCycle(double dutyCycle) {
48     pwmController.setPwmDutyCycle(dutyCycle);
49 }
50
51 public void setAngle(int angle) {
52     if (angle > 180 || angle < 0) {
53         return;
54     }
55     double dutyCycle = (((double) angle / 180.0 * 2) + 0.5) / 20;
56     pwmController.setPwmDutyCycle(dutyCycle);
57 }
58
59 public void shutdown() {
60     pwmController.requestStop();
61     pi4j.shutdown();
62 }
63 }
64
65 public class Sweep {
66     private static int SERVO_PIN = 18;
67     private static final Map<Integer, Servo> servoMap = new HashMap<>();
68
69     public static void myPrintln(String format, Object... args) {
70         Console console = new Console();
71         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
72     }
73
74     public static void main(String[] args) throws Exception {
75         servoMap.put(SERVO_PIN, new Servo(SERVO_PIN));
76         Servo servo = servoMap.get(SERVO_PIN);
77         servo.setFrequency(50);
78         servo.setDutyCycle(0.075);
79
80         myPrintln("Start sweeping ...");
81         Thread.sleep(3000);
82
83         try {
84             while (true) {
85                 for (int i = 0; i < 180; i++) {
86                     servo.setAngle(i);
87                     myPrintln("The Angle is %d", i);
```

```

88         Thread.sleep(20);
89     }
90     for (int i = 180; i > 0; i--) {
91         servo.setAngle(i);
92         myPrintln("The Angle is %d", i);
93         Thread.sleep(20);
94     }
95 }
96 } finally {
97     if (servo != null) {
98         servo.shutdown();
99     }
100 }
101 }
102 }
```

Servo constructor, initializes the servo control pins, and adds a JVM shutdown hook to ensure that the PWM controller and Pi4J context are properly closed when the program exits.

```

public Servo(int pin) throws Exception {
    this.pin = pin;
    this.pi4j = Pi4J.newAutoContext();
    DigitalOutput pwm = pi4j.dout().create(pin);
    this.pwmController = new PWMController(pwm);
    Thread pwmThread = new Thread(pwmController, "PWM for Servo on PIN " + pin);
    pwmThread.start();

    Runtime.getRuntime().addShutdownHook(new Thread(() -> {
        pwmController.requestStop();
        try {
            pwmThread.join();
        } catch (InterruptedException e) {
            Thread.currentThread().interrupt();
        }
    }));
}
```

Set the PWM duty cycle according to the angle to control the servo to rotate to the specified position.

```

public void setAngle(int angle) {
    if (angle > 180 || angle < 0) {
        return;
    }
    double dutyCycle = (((double) angle / 180.0 * 2) + 0.5) / 20;
    pwmController.setPwmDutyCycle(dutyCycle);
}
```



Initialize the servo controller and store it in servoMap.

```
servoMap.put(SERVO_PIN, new Servo(SERVO_PIN));
```

Get the servo controller from servoMap.

```
Servo servo = servoMap.get(SERVO_PIN);
```

The signal period of the servo is 20ms. According to the formula  $f=1/T$ , the frequency of the servo is set to 50Hz.

To control the servo to rotate to 0 degrees, a 1.5ms high level is required.  $1.5\text{ms}/20\text{ms}=0.075$ , so the duty cycle of the servo is 0.075. Similarly, if you want the servo to rotate to 180 degrees, a 2.5ms high level is required,  $2.5\text{ms}/20\text{ms}=0.375$ . You only need to modify the duty cycle value to control the rotation of the servo.

```
servo.setFrequency(50);  
servo.setDutyCycle(0.075);
```

The main code controls the servo to rotate between 0-180 degrees and prints prompt information on the terminal interface.

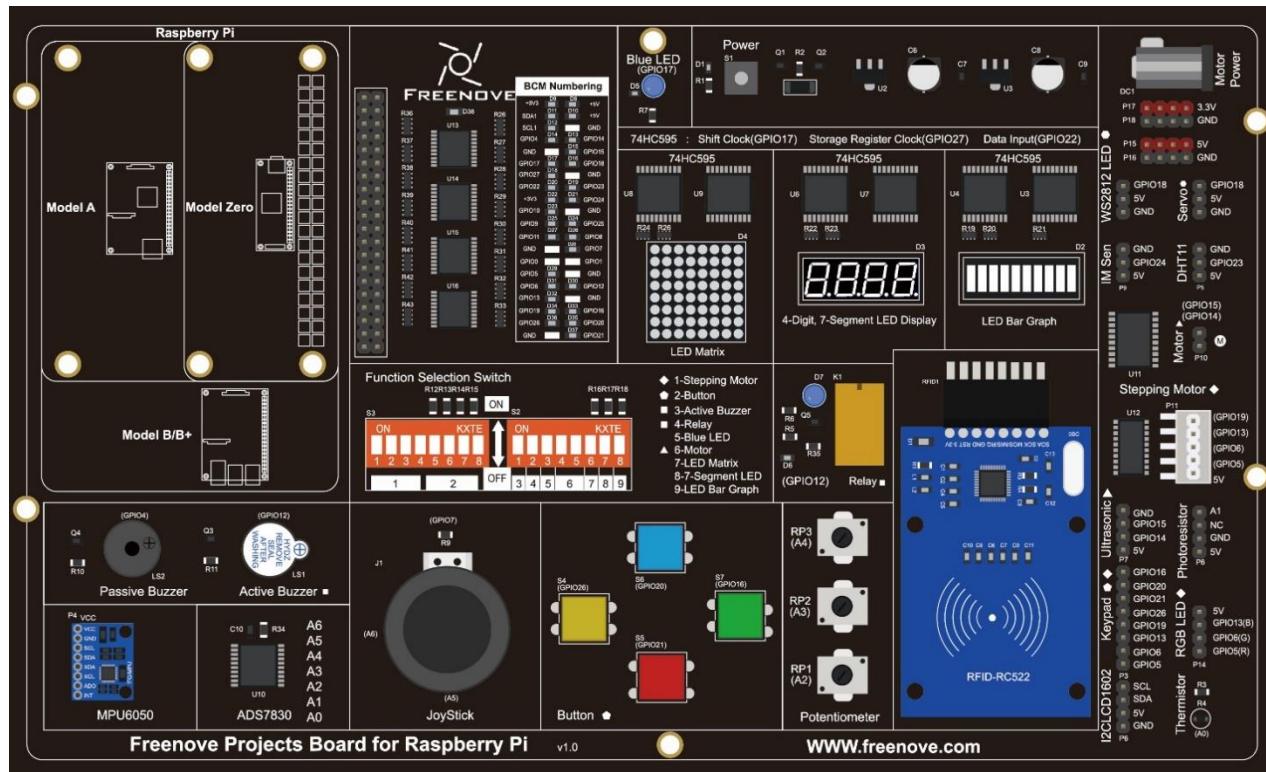
```
while (true) {  
    for (int i = 0; i < 180; i++) {  
        servo.setAngle(i);  
        myPrintln("The Angle is %d", i);  
        Thread.sleep(20);  
    }  
    for (int i = 180; i > 0; i--) {  
        servo.setAngle(i);  
        myPrintln("The Angle is %d", i);  
        Thread.sleep(20);  
    }  
}
```

## Project 13.2 Knob

In this project, we will learn how to control the servo with a potentiometer.

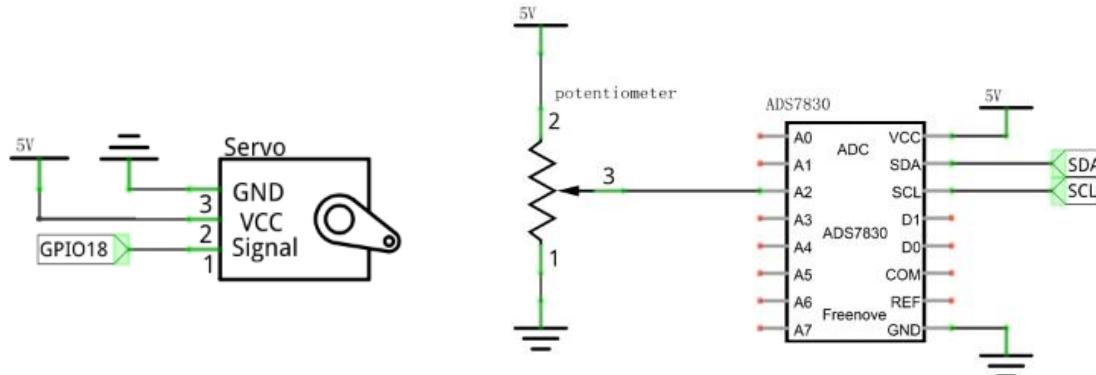
### Component List

Freenove Projects Board for Raspberry Pi

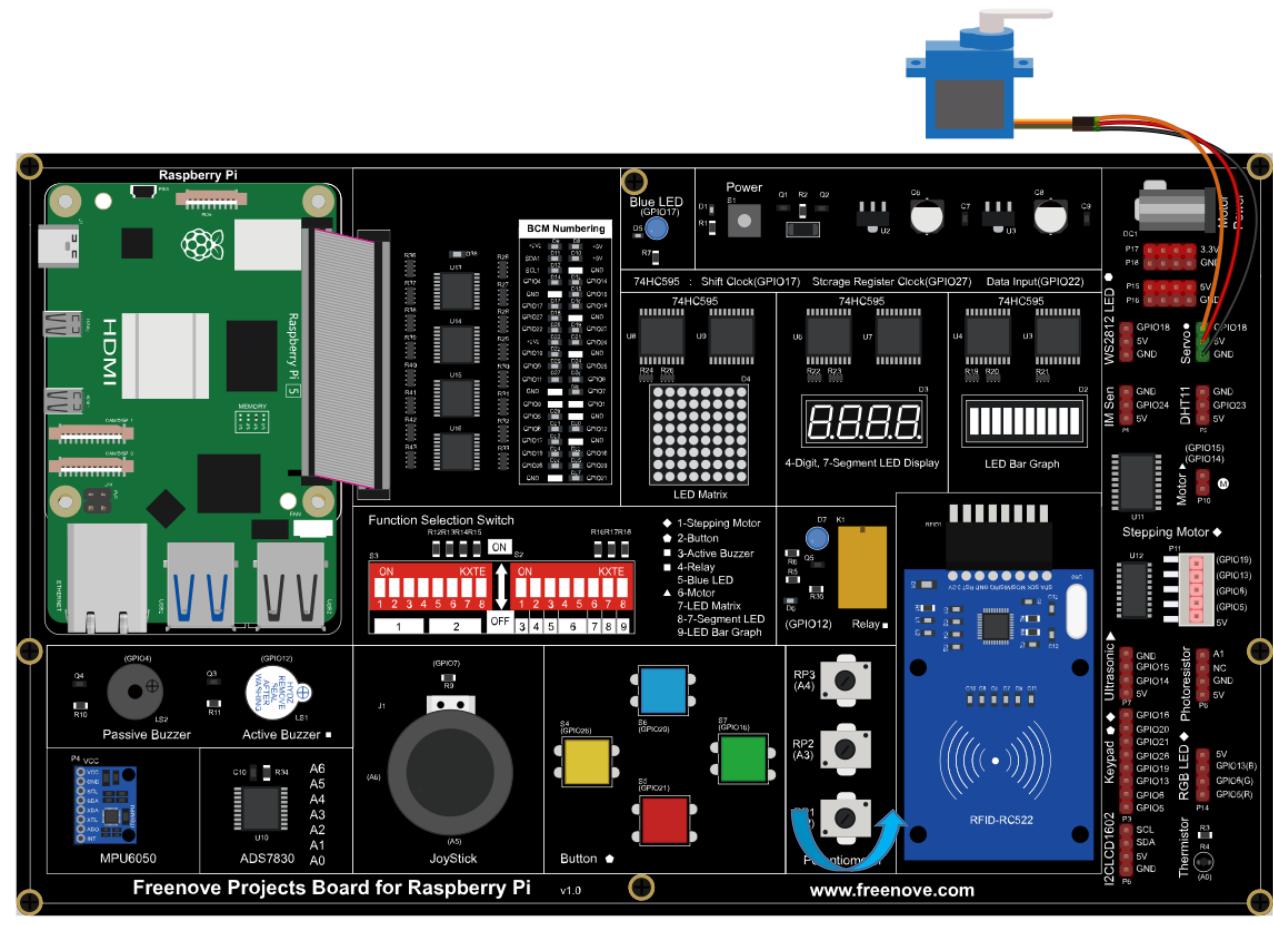


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this project, we will control the servo to rotate to a designated position by rotating the potentiometer.

### Sketch\_13\_2\_Knob

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_13_2_Knob
```

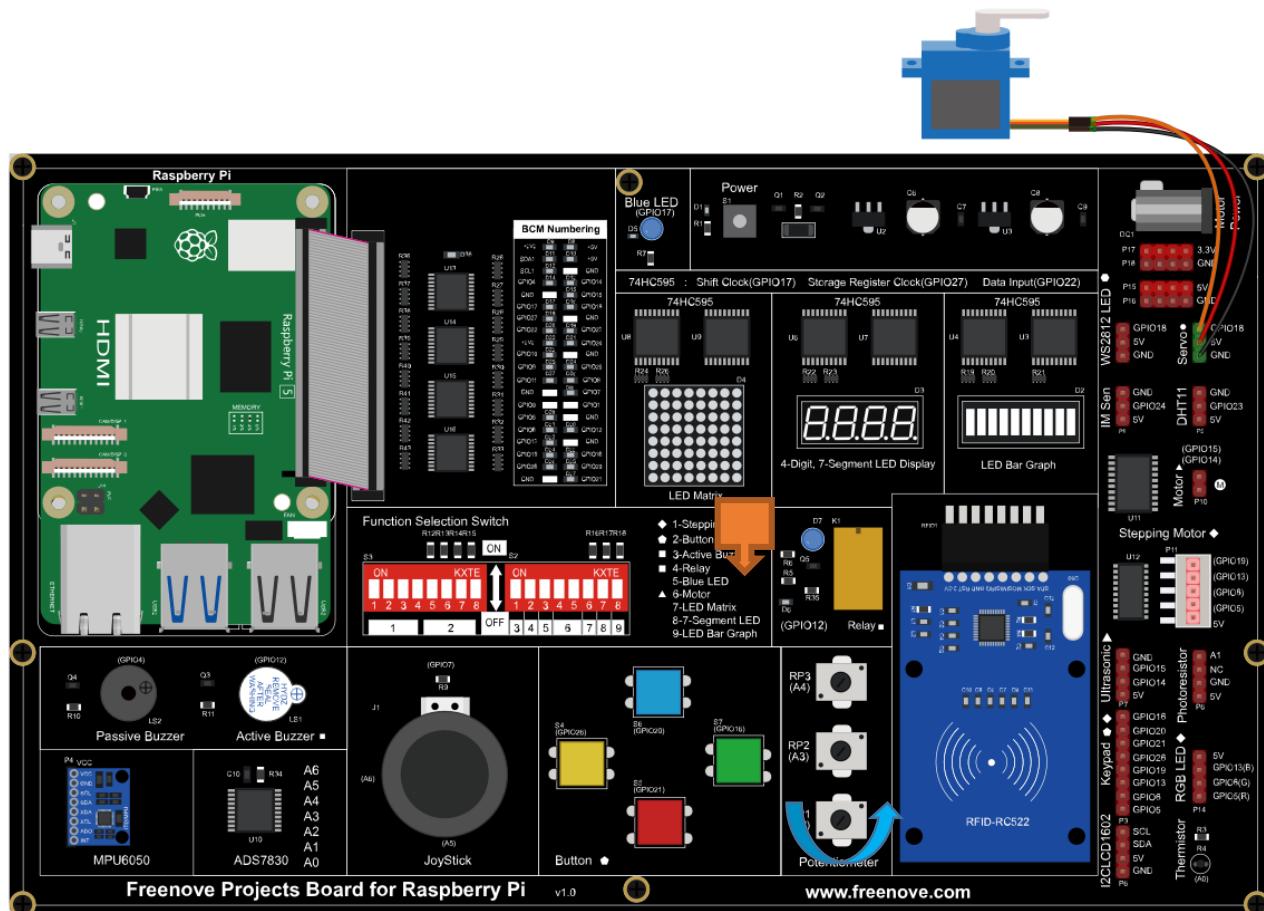
```
pi@raspberrypi:~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_13_2_Knob/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_13_2_Knob $
```

Enter the command to run the code.

```
jbang Knob.java
```

```
pi@raspberrypi:~ $ cd Freenove_Kit/Pi4j/Sketches/Sketch_13_2_Knob/
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_13_2_Knob $ jbang Knob.java
```

When the code is running, rotating the potentiometer and you can see the servo angle change.



On the terminal, you can see messages printed.

```
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:102, angle value is 72
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:122, angle value is 86
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:141, angle value is 99
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:156, angle value is 110
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:171, angle value is 120
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:183, angle value is 129
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:209, angle value is 147
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:242, angle value is 170
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:255, angle value is 180
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:255, angle value is 180
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:254, angle value is 179
```

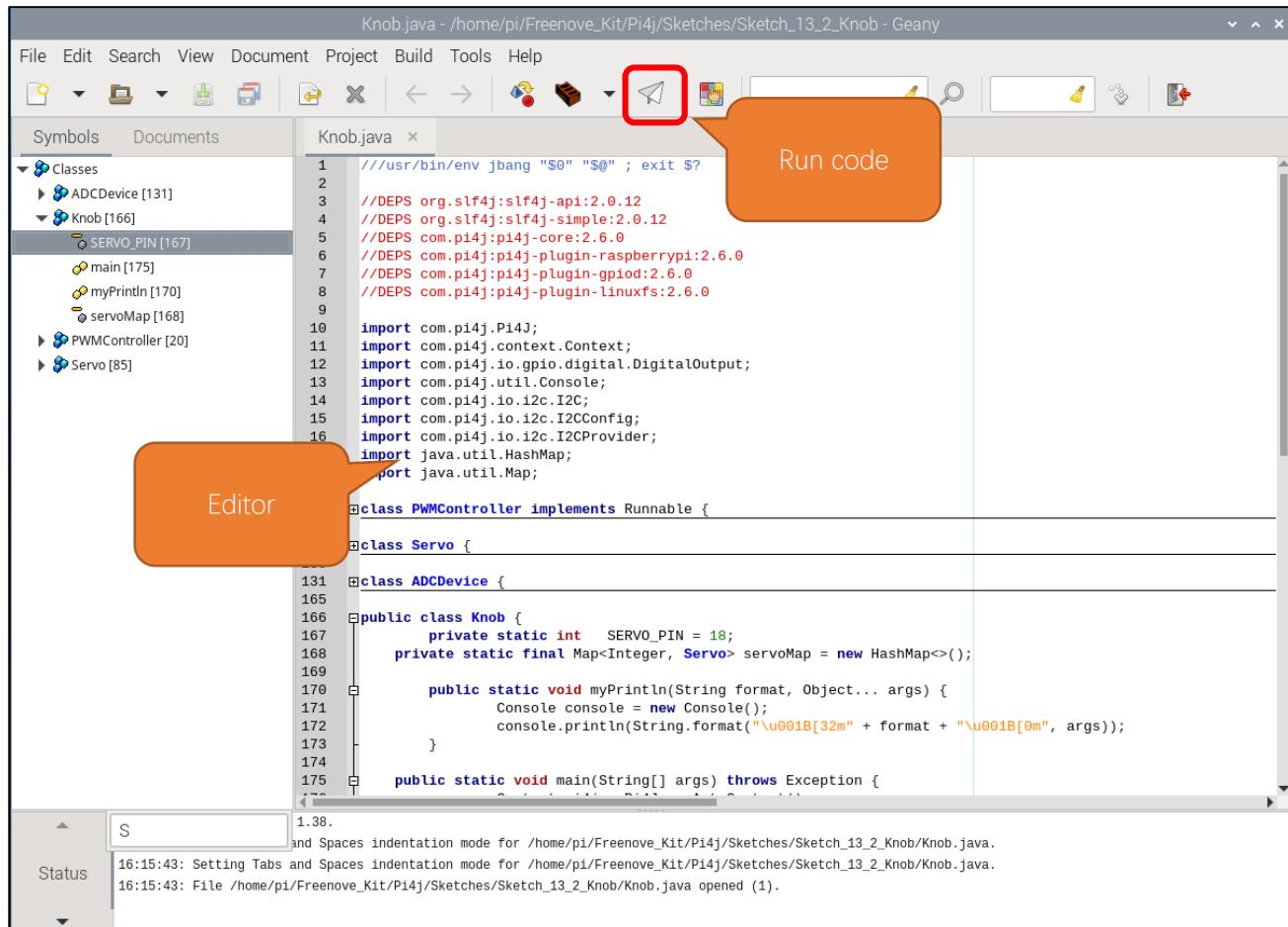
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:255, angle value is 180
[main] INFO com.pi4j.util.Console - ADC Channel 2 Value is:254, angle value is 179
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
```

You can run the following command to open the code with Geany to view and edit it.

## geany Knob.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //!/usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
9
10 import com.pi4j.Pi4J;
11 import com.pi4j.context.Context;
12 import com.pi4j.io.gpio.digital.DigitalOutput;
13 import com.pi4j.util.Console;
14 import com.pi4j.io.i2c.I2C;
15 import com.pi4j.io.i2c.I2CConfig;
16 import com.pi4j.io.i2c.I2CProvider;
17 import java.util.HashMap;
18 import java.util.Map;
19
20 class PWMController implements Runnable {
...
    ....
83 }
84
85 class Servo {
...
    ....
129 }
130
131 class ADCDevice {
...
    ....
164 }
165
166 public class Knob {
167     private static int SERVO_PIN = 18;
168     private static final Map<Integer, Servo> servoMap = new HashMap<>();
169
170     public static void myPrintln(String format, Object... args) {
171         Console console = new Console();
172         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
173     }
174
175     public static void main(String[] args) throws Exception {
176         Context pi4j = Pi4J.newAutoContext();
177         I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
```



```
178     servoMap.put(SERVO_PIN, new Servo(SERVO_PIN));
179
180
181     Servo servo = servoMap.get(SERVO_PIN);
182     servo.setFrequency(50);
183     servo.setDutyCycle(0.075);
184
185     myPrintln("Start sweeping ...");
186     Thread.sleep(1000);
187     try {
188         int ADC_CHIP_ADDR = 0x48;
189         ADCDevice adcDevice = new ADCDevice(pi4j, i2CProvider, ADC_CHIP_ADDR);
190
191         if (adcDevice.detectI2C()) {
192             int ADC_CHANNEL = 2;
193             while (true) {
194                 int adcValue = adcDevice.analogRead(ADC_CHANNEL);
195                 int angle = (int)((double)adcValue/255.0*180);
196                 if (adcValue != -1) {
197                     myPrintln("ADC Channel %d Value is:%d, angle value is %d",
198                             ADC_CHANNEL, adcValue, angle);
199                     servo.setAngle(angle);
200                 } else {
201                     myPrintln("Failed to read data from ADC.");
202                 }
203                 Thread.sleep(100);
204             }
205         } else {
206             myPrintln("ADS7830 device not detected at address 0x" +
207                     Integer.toHexString(ADC_CHIP_ADDR));
208         }
209     finally {
210         if (servo != null) {
211             servo.shutdown();
212         }
213     }
214 }
```

The ADC value at the potentiometer is obtained every 100 milliseconds and is converted into an angle value, which is provided to the servo angle control function, and a prompt message is printed on the terminal interface.

```
if (adcDevice.detectI2C()) {  
    int ADC_CHANNEL = 2;  
    while (true) {  
        int adcValue = adcDevice.analogRead(ADC_CHANNEL);  
        int angle = (int)((double)adcValue/255.0*180);  
        if (adcValue != -1) {  
            myPrintln("ADC Channel %d Value is:%d, angle value is %d",  
                ADC_CHANNEL, adcValue, angle);  
            servo.setAngle(angle);  
        } else {  
            myPrintln("Failed to read data from ADC.");  
        }  
        Thread.sleep(100);  
    }  
}
```

# Chapter 14 Stepper Motor

Thus far, we have learned about DC Motors and Servos. A DC motor can rotate constantly in one direction but we cannot control the rotation to a specific angle. On the contrary, a Servo can rotate to a specific angle but cannot rotate constantly in one direction. In this chapter, we will learn about a Stepper Motor which is also a type of motor. A Stepper Motor can rotate constantly and also to a specific angle. Using a Stepper Motor can easily achieve higher accuracies in mechanical motion.

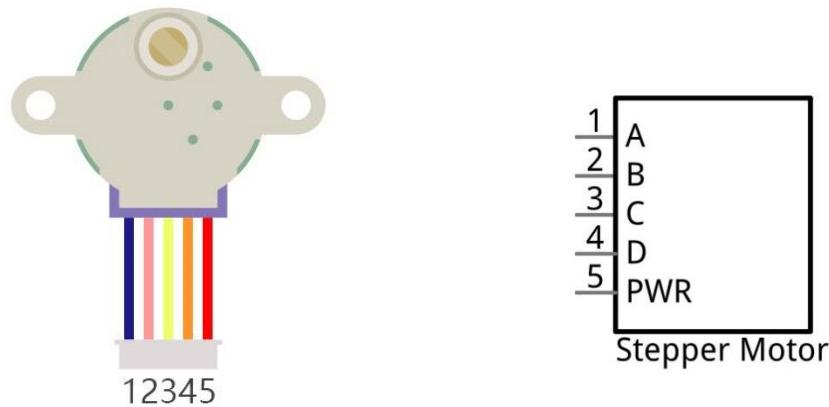
## Project 14.1 Stepper Motor

In this project, we will learn how to drive a Stepper Motor, and understand its working principle.

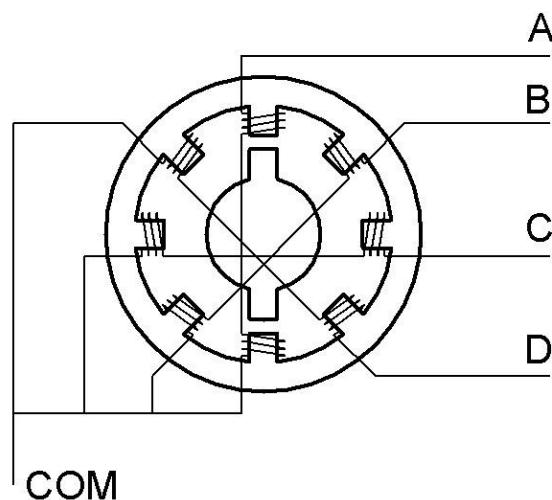
### Component knowledge

#### Stepper Motor

Stepper Motors are an open-loop control device, which converts an electronic pulse signal into angular displacement or linear displacement. In a non-overload condition, the speed of the motor and the location of the stops depends only on the pulse signal frequency and number of pulses and is not affected by changes in load as with a DC Motor. A small Four-Phase Deceleration Stepper Motor is shown here:

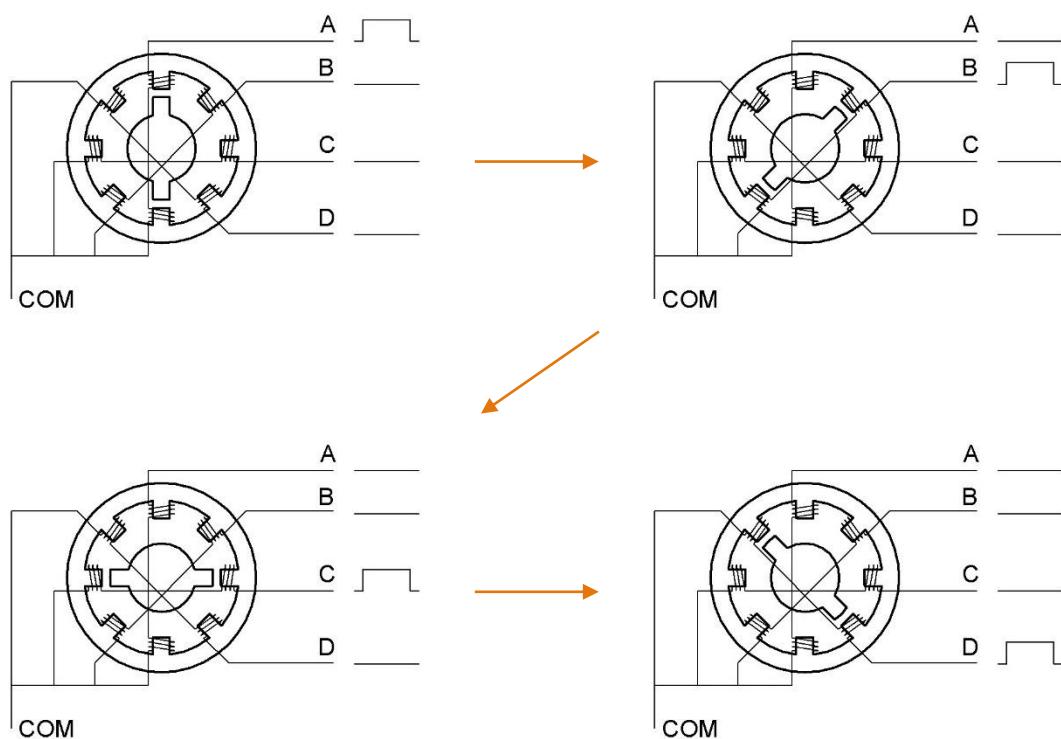


The electronic schematic diagram of a Four-Phase Stepper Motor is shown below:



The outside case or housing of the Stepper Motor is the Stator and inside the Stator is the Rotor. There is a specific number of individual coils, usually an integer multiple of the number of phases the motor has, when the Stator is powered ON, an electromagnetic field will be formed to attract a corresponding convex diagonal groove or indentation in the Rotor's surface. The Rotor is usually made of iron or a permanent magnet. Therefore, the Stepper Motor can be driven by powering the coils on the Stator in an ordered sequence (producing a series of "steps" or stepped movements).

A common driving sequence is shown here:



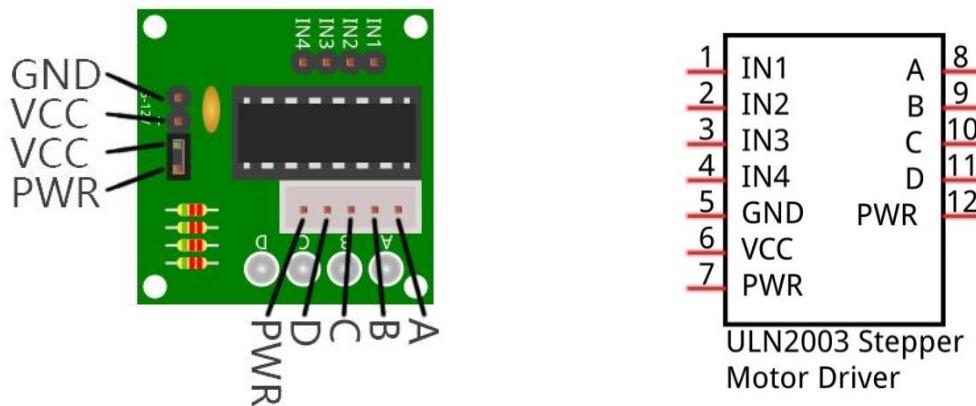
In the sequence above, the Stepper Motor rotates by a certain angle at once, which is called a “step”. By controlling the number of rotational steps, you can then control the Stepper Motor’s rotation angle. By defining the time between two steps, you can control the Stepper Motor’s rotation speed. When rotating clockwise, the order of coil powered on is: A → B → C → D → A →…… . And the rotor will rotate in accordance with this order, step by step, called four-steps, four-part. If the coils is powered ON in the reverse order, D → C → B → A → D →…… , the rotor will rotate in counter-clockwise direction.

There are other methods to control Stepper Motors, such as: connect A phase, then connect A B phase, the stator will be located in the center of A B, which is called a half-step. This method can improve the stability of the Stepper Motor and reduces noise. Tise sequence of powering the coils looks like this: A → AB → B → BC → C → CD → D → DA → A →…… , the rotor will rotate in accordance to this sequence ar, a half-step at a time, called four-steps, eight-part. Conversely, if the coils are powered ON in the reverse order the Stepper Motor will rotate in the opposite direction.

The stator in the Stepper Motor we have supplied has 32 magnetic poles. Therefore, to complete one full revolution requires 32 full steps. The rotor (or output shaft) of the Stepper Motor is connected to a speed reduction set of gears and the reduction ratio is 1:64. Therefore, the final output shaft (exiting the Stepper Motor’s housing) requires  $32 \times 64 = 2048$  steps to make one full revolution.

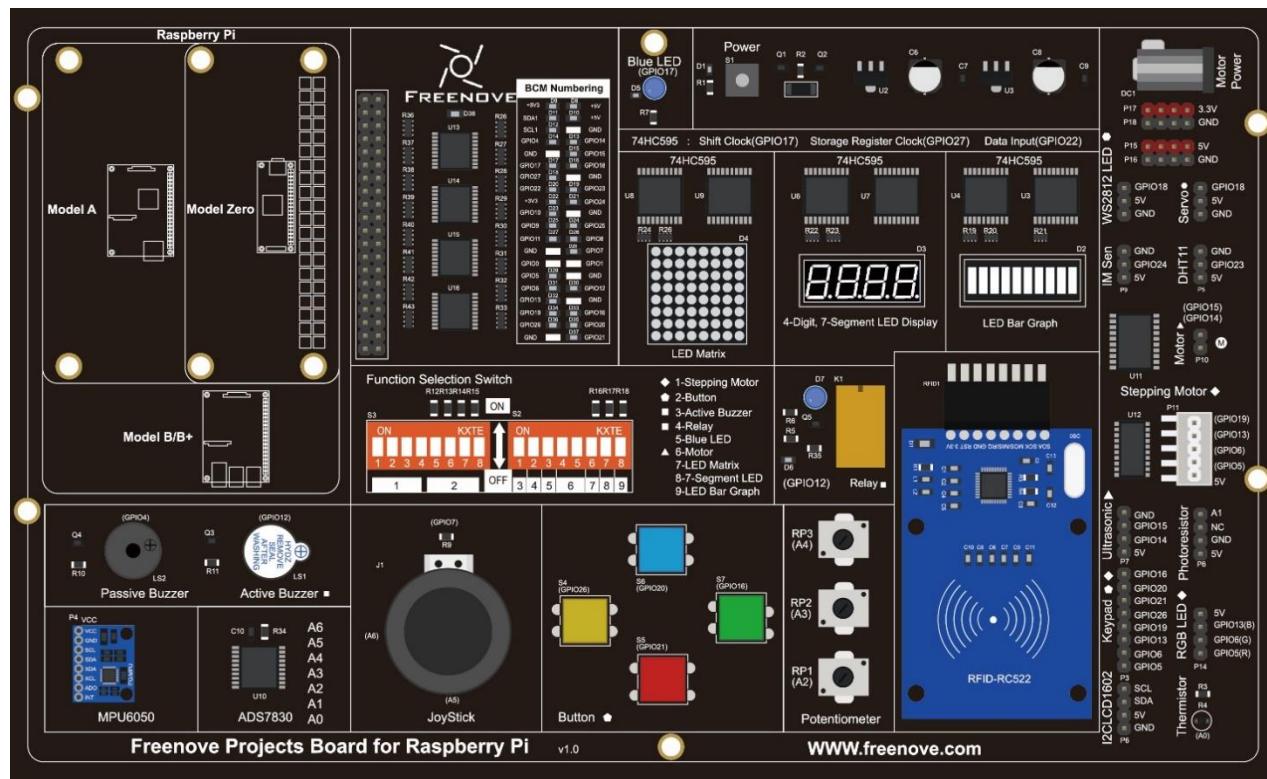
#### ULN2003 Stepper Motor driver

A ULN2003 Stepper Motor Driver is used to convert weak signals into more powerful control signals in order to drive the Stepper Motor. In the illustration below, the input signal IN1-IN4 corresponds to the output signal A-D, and 4 LEDs are integrated into the board to indicate the state of these signals. The PWR interface can be used as a power supply for the Stepper Motor. By default, PWR and VCC are connected.

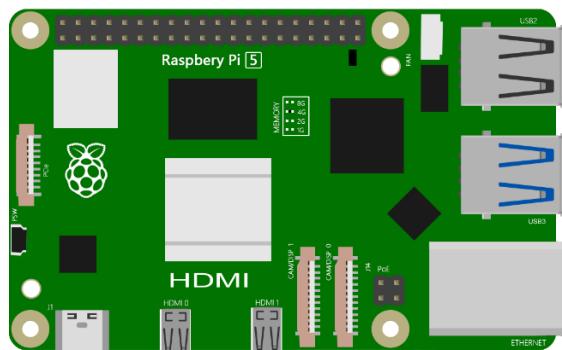


## Component List

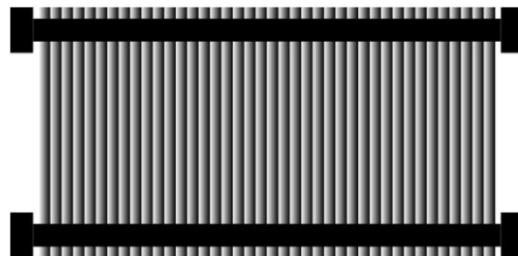
Freenove Projects Board for Raspberry Pi



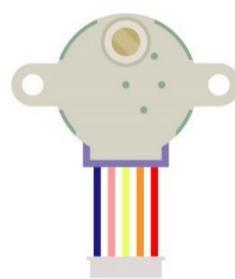
Raspberry Pi



GPIO Ribbon Cable



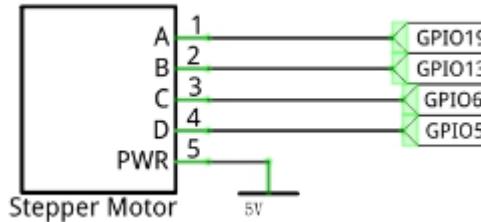
Stepper Motor



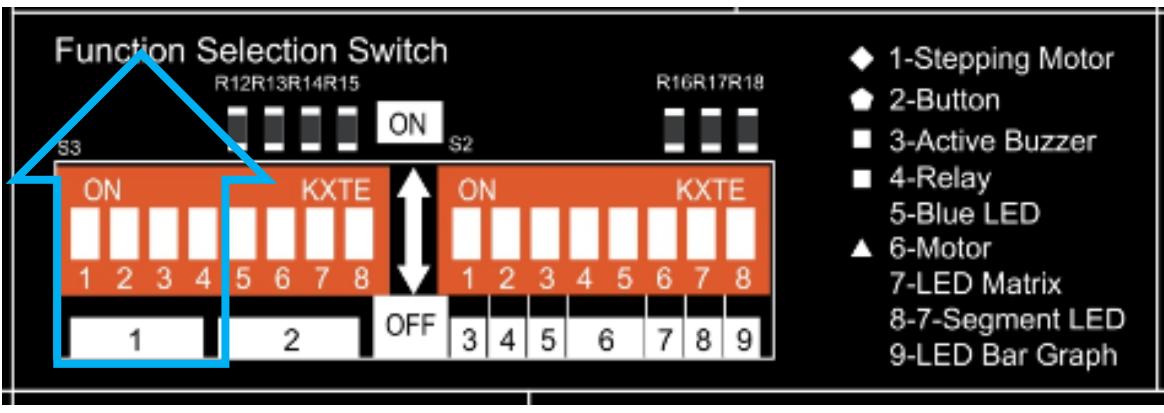
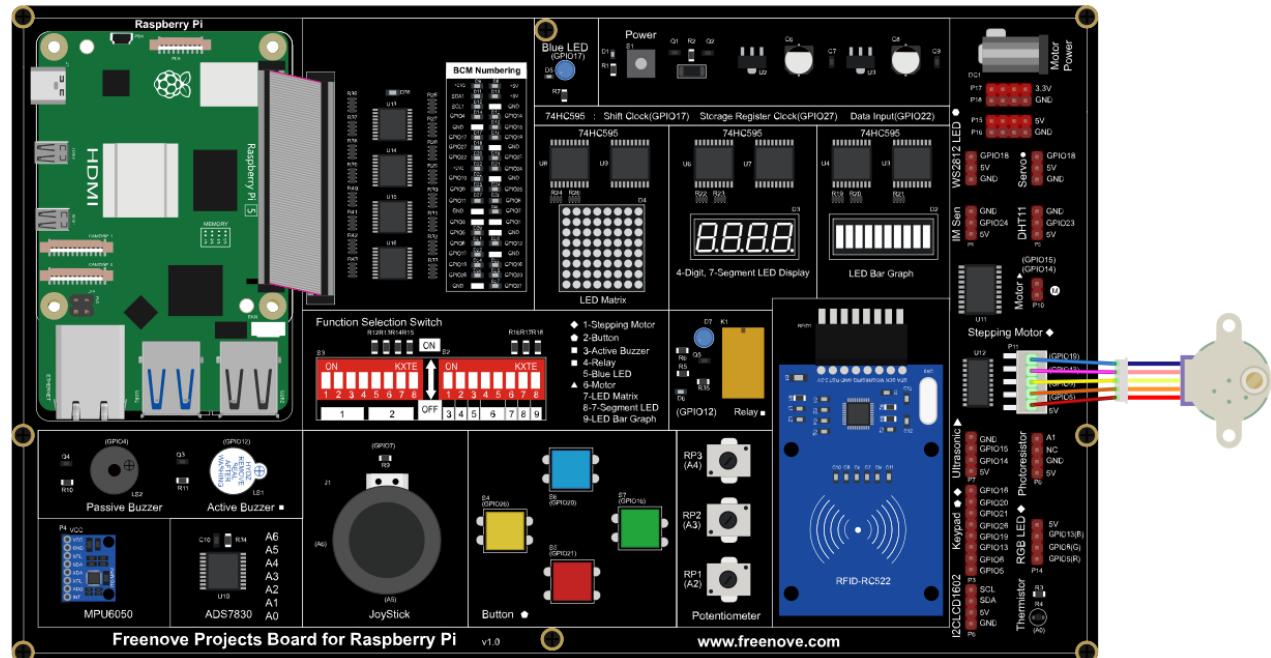


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this project, we will use a stepper motor.

### Sketch\_14\_SteppingMotor

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_14_SteppingMotor
```

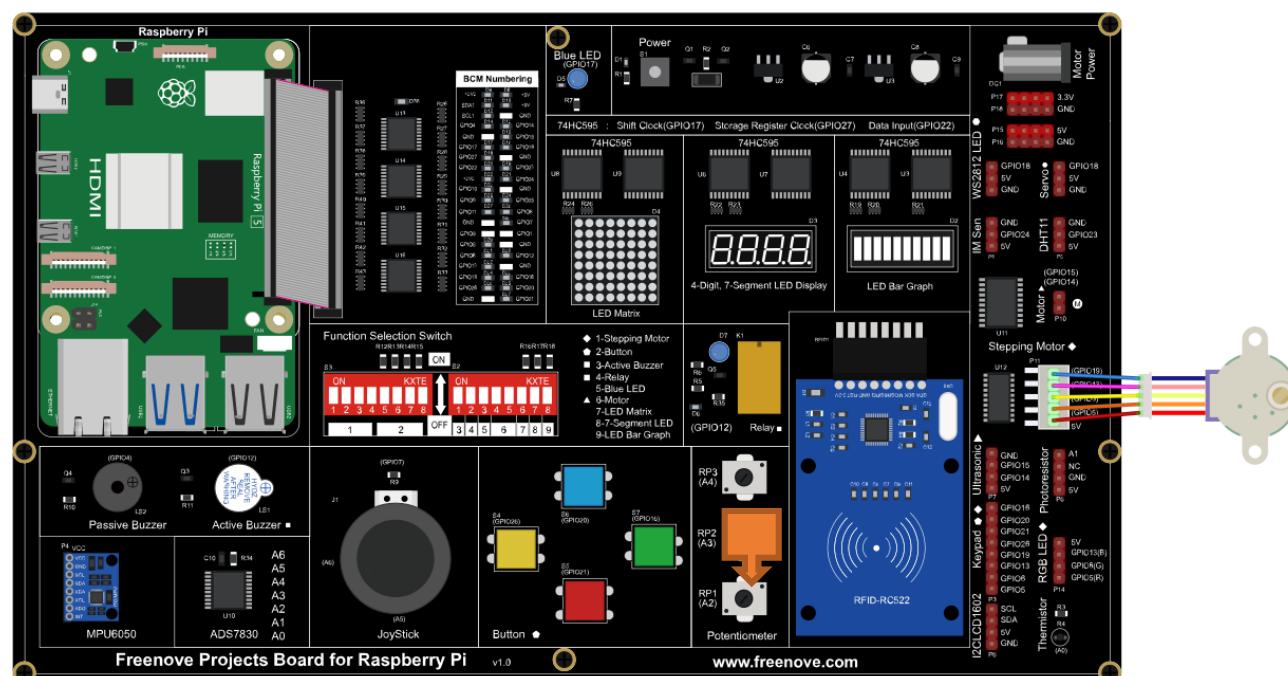
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_14_SteppingMotor
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_14_SteppingMotor $
```

Enter the command to run the code.

```
jbang SteppingMotor.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_14_SteppingMotor
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_14_SteppingMotor $ jbang SteppingMotor.java
```

When the code is running, you can observe that the stepper motor first rotates one circle forward, then one circle reversely, and repeats this process back and forth.



On the terminal, you can see the messages printed.

```
[main] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully initialized.
[main] INFO com.pi4j.util.Console - Stepper motor is turning...
[main] INFO com.pi4j.util.Console - stepper motor is reversing...
[main] INFO com.pi4j.util.Console - Stepper motor is turning...
[main] INFO com.pi4j.util.Console - stepper motor is reversing...
```

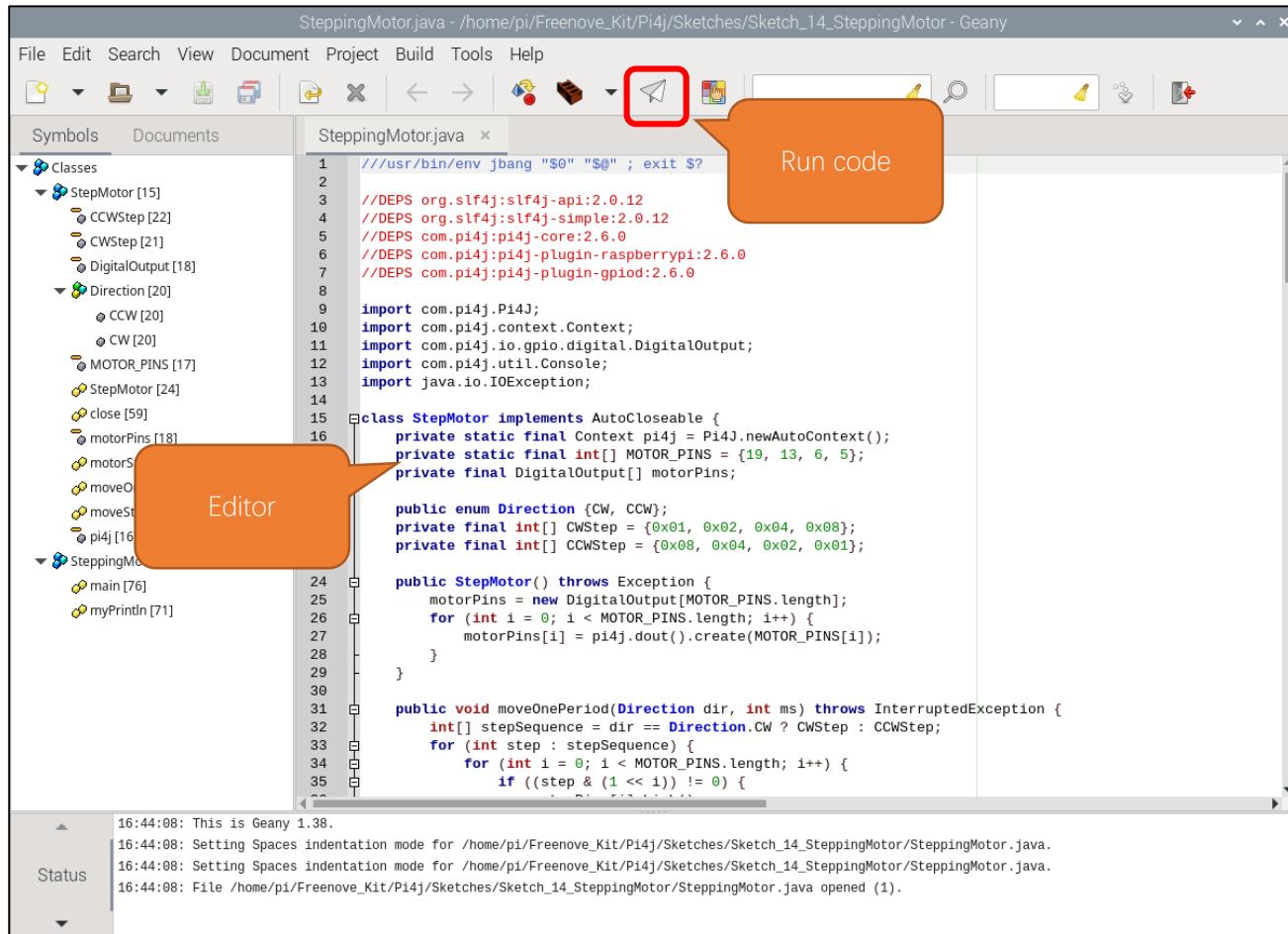
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.util.Console - Stepper motor is turning...
[main] INFO com.pi4j.util.Console - stepper motor is reversing...
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown.
Dispatching shutdown event.
```

You can run the following command to open the code with Geany to view and edit it.

### geany SteppingMotor.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1  //!/usr/bin/env jbang "$0" "$@" ; exit $?
2
3  //DEPS org.slf4j:slf4j-api:2.0.12
4  //DEPS org.slf4j:slf4j-simple:2.0.12
5  //DEPS com.pi4j:pi4j-core:2.6.0
6  //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7  //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9  import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.digital.DigitalOutput;
12 import com.pi4j.util.Console;
13 import java.io.IOException;
14
15 class StepMotor implements AutoCloseable {

```

```
16     private static final Context pi4j = Pi4J.newAutoContext();
17     private static final int[] MOTOR_PINS = {19, 13, 6, 5};
18     private final DigitalOutput[] motorPins;
19
20     public enum Direction {CW, CCW};
21     private final int[] CWStep = {0x01, 0x02, 0x04, 0x08};
22     private final int[] CCWStep = {0x08, 0x04, 0x02, 0x01};
23
24     public StepMotor() throws Exception {
25         motorPins = new DigitalOutput[MOTOR_PINS.length];
26         for (int i = 0; i < MOTOR_PINS.length; i++) {
27             motorPins[i] = pi4j.dout().create(MOTOR_PINS[i]);
28         }
29     }
30
31     public void moveOnePeriod(Direction dir, int ms) throws InterruptedException {
32         int[] stepSequence = dir == Direction.CW ? CWStep : CCWStep;
33         for (int step : stepSequence) {
34             for (int i = 0; i < MOTOR_PINS.length; i++) {
35                 if ((step & (1 << i)) != 0) {
36                     motorPins[i].high();
37                 } else {
38                     motorPins[i].low();
39                 }
40             }
41             if (ms < 3) ms = 3;
42             Thread.sleep(ms);
43         }
44     }
45
46     public void moveSteps(Direction dir, int ms, int steps) throws InterruptedException {
47         for (int i = 0; i < steps; i++) {
48             moveOnePeriod(dir, ms);
49         }
50     }
51
52     public void motorStop() {
53         for (DigitalOutput pin : motorPins) {
54             pin.low();
55         }
56     }
57
58     @Override
59     public void close() throws Exception {
```



```
60     for (DigitalOutput pin : motorPins) {
61         if (pin != null) {
62             pin.low();
63         }
64     }
65     pi4j.shutdown();
66 }
67 }
68
69 public class SteppingMotor {
70     public static void myPrintln(String format, Object... args) {
71         Console console = new Console();
72         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
73     }
74
75     public static void main(String[] args) {
76         StepMotor motorControl = null;
77         try {
78             motorControl = new StepMotor();
79             Runtime.getRuntime().addShutdownHook(new Thread(motorControl::motorStop));
80             while (true) {
81                 myPrintln("Stepper motor is turning...");
82                 motorControl.moveSteps(StepMotor.Direction.CW, 3, 512);
83                 Thread.sleep(500);
84                 myPrintln("stepper motor is reversing...");
85                 motorControl.moveSteps(StepMotor.Direction.CCW, 3, 512);
86                 Thread.sleep(500);
87             }
88         } catch (InterruptedException e) {
89             Thread.currentThread().interrupt();
90             myPrintln("Interrupted: %s", e.getMessage());
91         } catch (Exception e) {
92             myPrintln("Error: %s", e.getMessage());
93         } finally {
94             if (motorControl != null) {
95                 try {
96                     motorControl.close();
97                 } catch (Exception ex) {
98                     ex.printStackTrace();
99                 }
100            }
101        }
102    }
103 }
```

Define the GPIO pins for motor control and the GPIO outputs used to control the motors.

```
private static final int[] MOTOR_PINS = {19, 13, 6, 5};
private final DigitalOutput[] motorPins;
```

Define the motor's rotation direction and the array of step sequences for clockwise and counter-clockwise directions.

```
public enum Direction {CW, CCW};
private final int[] CWStep = {0x01, 0x02, 0x04, 0x08};
private final int[] CCWStep = {0x08, 0x04, 0x02, 0x01};
```

Constructor, initialize GPIO pins.

```
public StepMotor() throws Exception {
    motorPins = new DigitalOutput[MOTOR_PINS.length];
    for (int i = 0; i < MOTOR_PINS.length; i++) {
        motorPins[i] = pi4j.dout().create(MOTOR_PINS[i]);
    }
}
```

Control the stepper motor to execute a one-step sequence cycle.

```
public void moveOnePeriod(Direction dir, int ms) throws InterruptedException {
    int[] stepSequence = dir == Direction.CW ? CWStep : CCWStep;
    for (int step : stepSequence) {
        for (int i = 0; i < MOTOR_PINS.length; i++) {
            if ((step & (1 << i)) != 0) {
                motorPins[i].high();
            } else {
                motorPins[i].low();
            }
        }
        if (ms < 3) ms = 3;
        Thread.sleep(ms);
    }
}
```

The stepper motor driving function controls the direction of motor rotation, the execution time of each stepping action, and the number of stepping sequences to execute.

```
public void moveSteps(Direction dir, int ms, int steps) throws InterruptedException {
    for (int i = 0; i < steps; i++) {
        moveOnePeriod(dir, ms);
    }
}
```

Stepper motor stop function that stops the motor.

```
public void motorStop() {
    for (DigitalOutput pin : motorPins) {
        pin.low();
    }
}
```



Implement the AutoCloseable interface to ensure that resources are released when they are no longer needed.

```
@Override
public void close() throws Exception {
    for (DigitalOutput pin : motorPins) {
        if (pin != null) {
            pin.low();
        }
    }
    pi4j.shutdown();
}
```

Initialize stepper motor controller.

```
motorControl = new StepMotor();
```

Add JVM shutdown hook to ensure motors are stopped on program exit.

```
Runtime.getRuntime().addShutdownHook(new Thread(motorControl::motorStop));
```

First, control the stepper motor to rotate forward one circle, then pause for 500 milliseconds, then control the stepper motor to rotate reversely one circle, then pause for 500 milliseconds, and repeat this process.

```
myPrintln("Stepper motor is turning... ");
motorControl.moveSteps(StepMotor.Direction.CW, 3, 512);
Thread.sleep(500);
myPrintln("stepper motor is reversing... ");
motorControl.moveSteps(StepMotor.Direction.CCW, 3, 512);
Thread.sleep(500);
```

If a thread termination exception or other exception occurs, it will be printed out on the terminal interface.

```
catch (InterruptedException e) {
    Thread.currentThread().interrupt();
    myPrintln("Interrupted: %s", e.getMessage());
} catch (Exception e) {
    myPrintln("Error: %s", e.getMessage());
}
```

Make sure the resources are released when the program ends.

```
finally {
    if (motorControl != null) {
        try {
            motorControl.close();
        } catch (Exception ex) {
            ex.printStackTrace();
        }
    }
}
```

# Chapter 15 74HC595 & Bar Graph LED

We have used LED Bar Graph to make a flowing water light, in which 10 GPIO ports of RPi are occupied. More GPIO ports mean that more peripherals can be connected to RPi, so GPIO resource is very precious. Can we make flowing water light with less GPIO ports? In this chapter, we will learn a component, 74HC595, which can achieve the target.

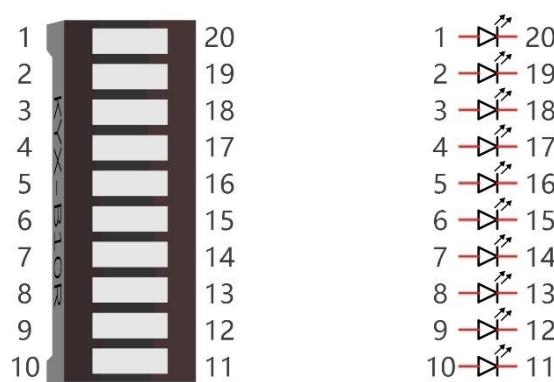
## Project 15.1 Flowing Water Light

Now let us learn how to use the 74HC595 IC Chip to make a flowing water light using less GPIO.

### Component knowledge

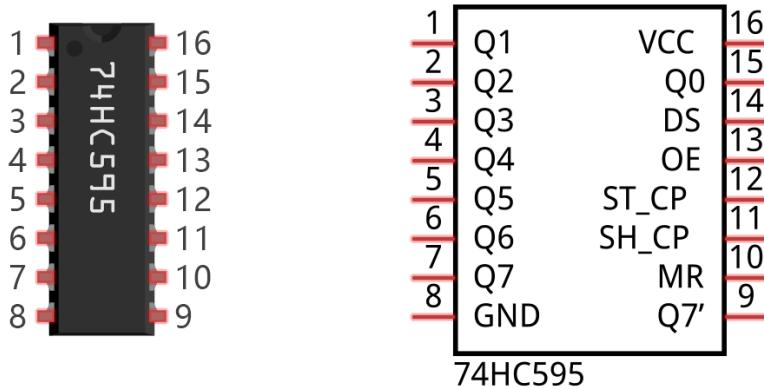
#### Bar Graph LED

A Bar Graph LED has 10 LEDs integrated into one compact component. The two rows of pins at its bottom are paired to identify each LED like the single LED used earlier.



**74HC595**

A 74HC595 chip is used to convert serial data into parallel data. A 74HC595 chip can convert the serial data of one byte into 8 bits, and send its corresponding level to each of the 8 ports correspondingly. With this characteristic, the 74HC595 chip can be used to expand the IO ports of a Raspberry Pi. At least 3 ports on the RPI board are required to control the 8 ports of the 74HC595 chip.



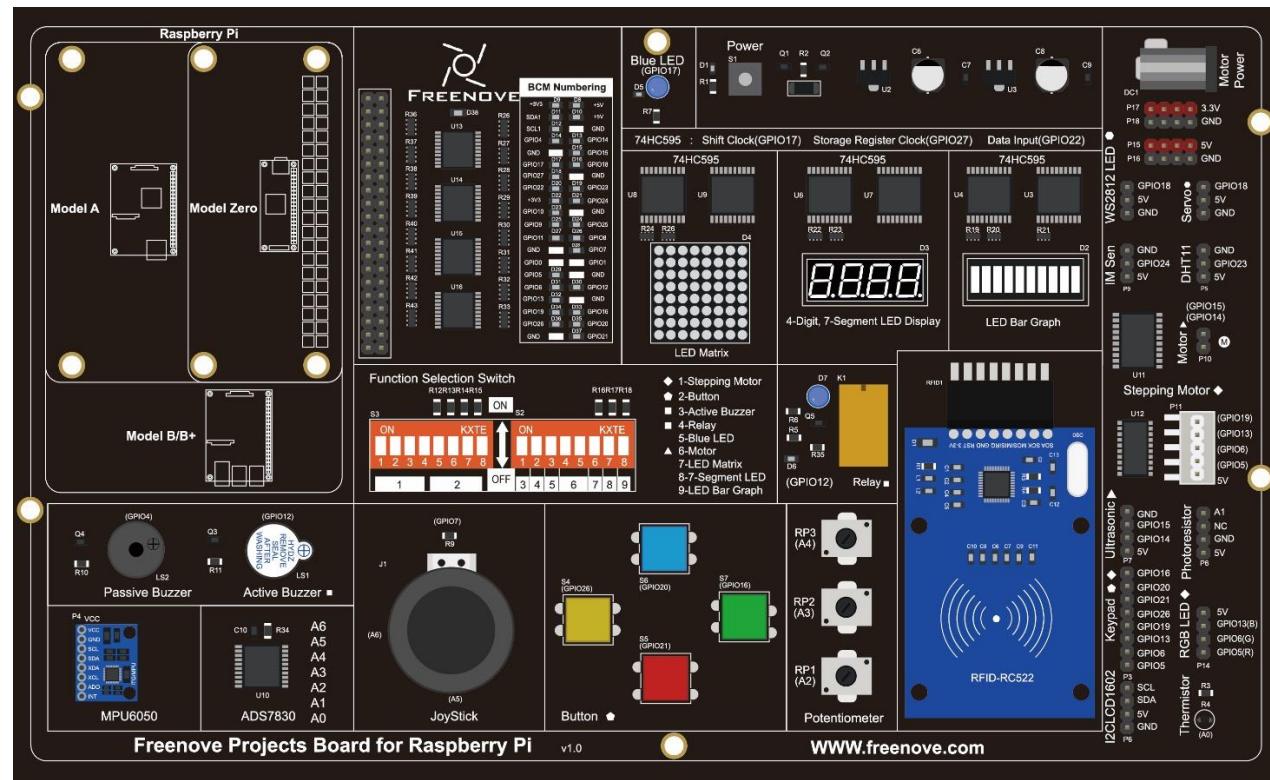
The ports of the 74HC595 chip are described as follows:

Pin name	Pin number	Description
Q0-Q7	15, 1-7	Parallel Data Output
VCC	16	The Positive Electrode of the Power Supply, the Voltage is 2~6V
GND	8	The Negative Electrode of Power Supply
DS	14	Serial Data Input
OE	13	Enable Output, When this pin is in high level, Q0-Q7 is in high resistance state When this pin is in low level, Q0-Q7 is in output mode
ST_CP	12	Parallel Update Output: when its electrical level is rising, it will update the parallel data output.
SH_CP	11	Serial Shift Clock: when its electrical level is rising, serial data input register will do a shift.
MR	10	Remove Shift Register: When this pin is in low level, the content in shift register will be cleared.
Q7'	9	Serial Data Output: it can be connected to more 74HC595 chips in series.

For more details, please refer to the datasheet on the 74HC595 chip.

## Component List

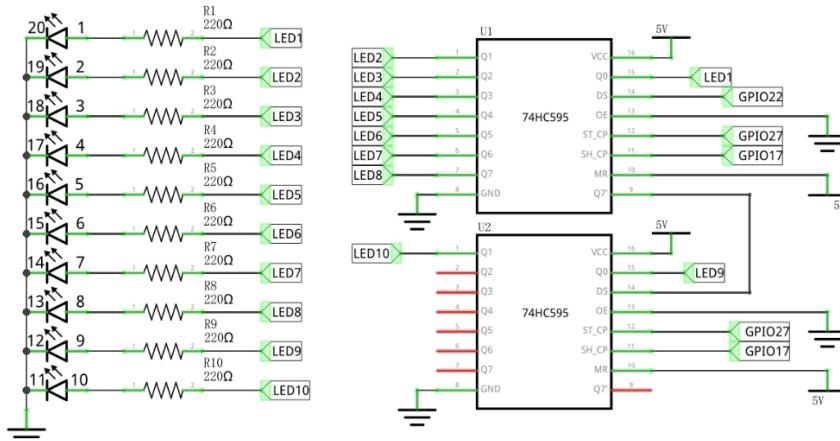
Freenove Projects Board for Raspberry Pi



<p>Raspberry Pi</p> <p>The diagram shows the front side of a Raspberry Pi Model B+ board. It features the Broadcom SoC, RAM chips, and various connectors. Key labels include 'Raspberry Pi 5', 'HDMI', 'ETHERNET', 'USB', and 'POWER'. A blue ribbon cable is shown next to the board.</p>	<p>GPIO Ribbon Cable</p> <p>A standard black ribbon cable with two rows of 26 pins each, used for connecting the Raspberry Pi's GPIO pins to external components.</p>
<p>Bar Graph LED</p> <p>A physical photograph of a bar graph LED component, showing a series of vertical segments that can be illuminated to represent numerical values.</p>	

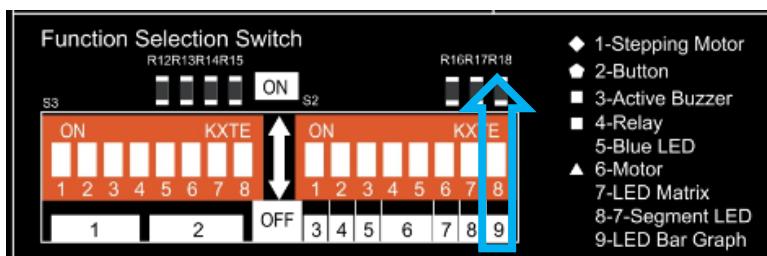
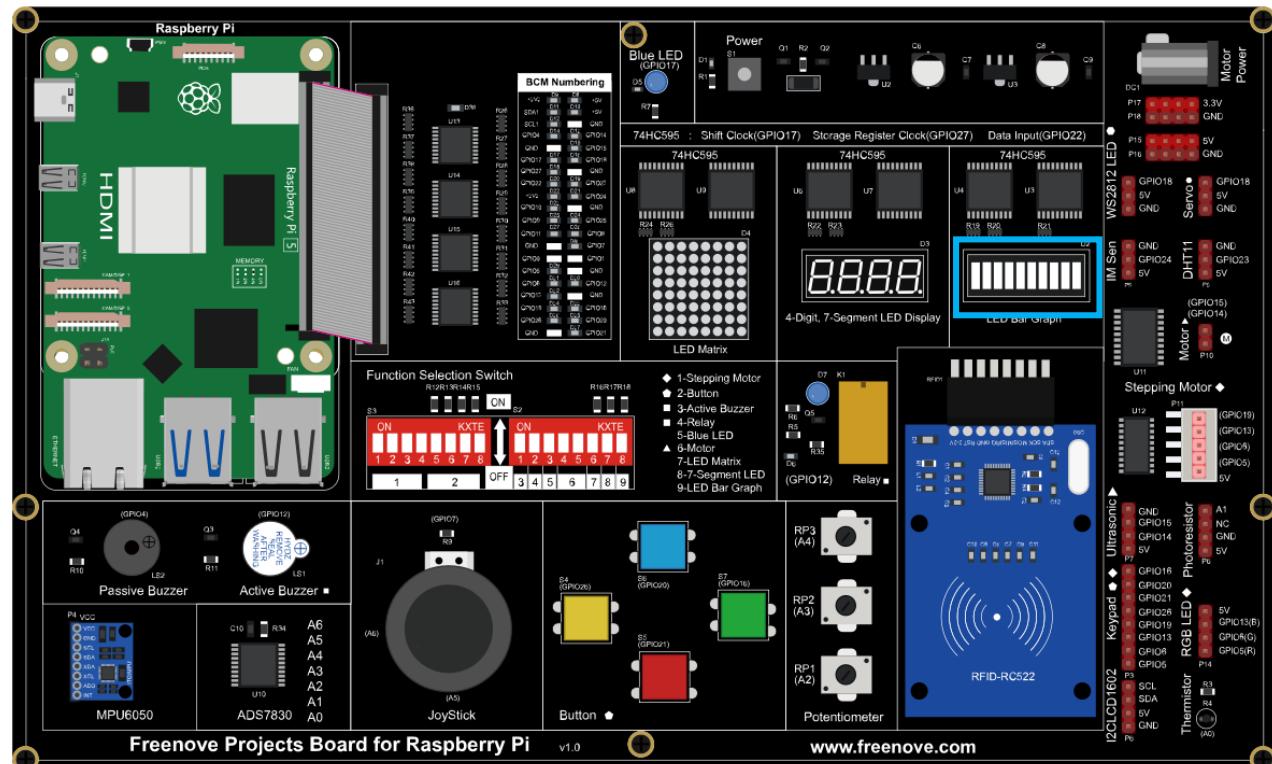
## Circuit

Schematic diagram



Hardware connection.

If it doesn't work, rotate the LED bar graph for 180°.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In this chapter, we will learn how to drive the LED Bar by expanding the chip.

### Sketch\_15\_FlowingLight02

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_15_FlowingLight02
```

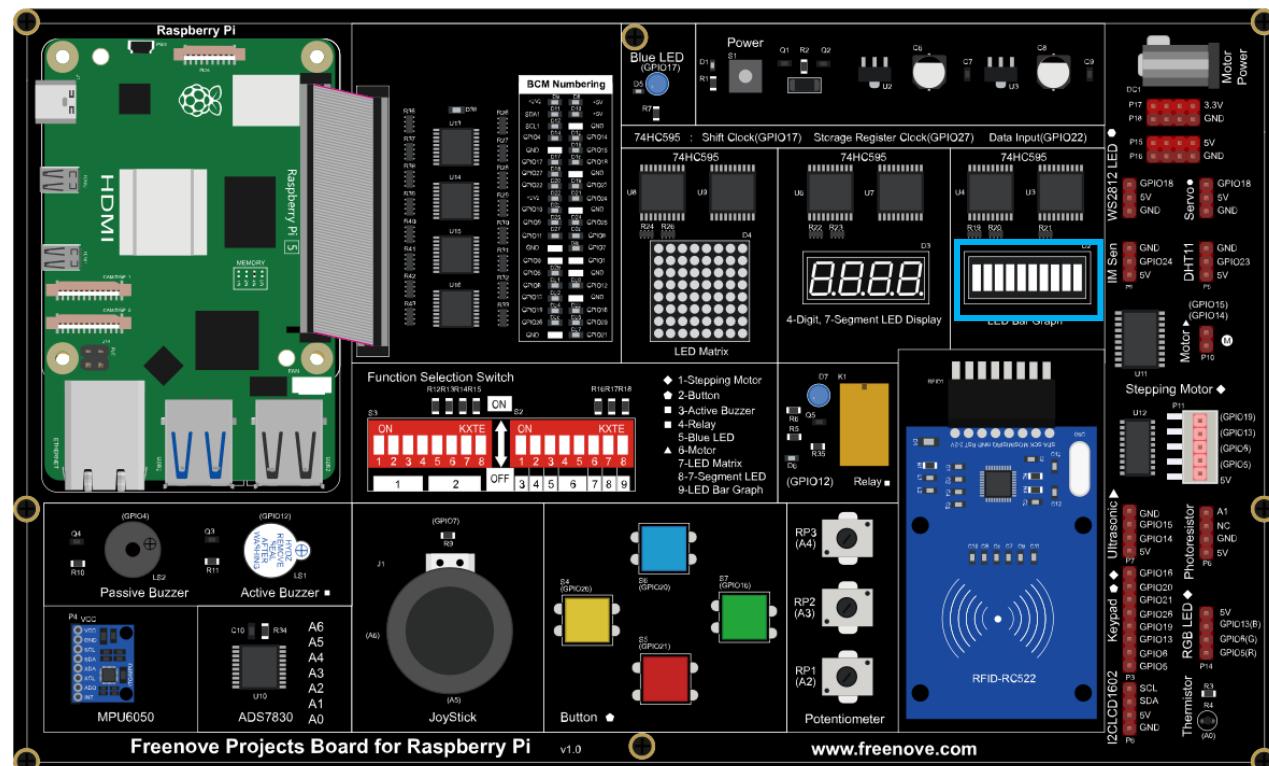
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_15_FlowingLight02
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_15_FlowingLight02 $
```

Enter the command to run the code.

```
jbang FlowingLight02.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_15_FlowingLight02
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_15_FlowingLight02 $ jbang FlowingLight02.java
```

When the code is running, you can see the LEDs of the LED bar light up in a flowing water pattern.



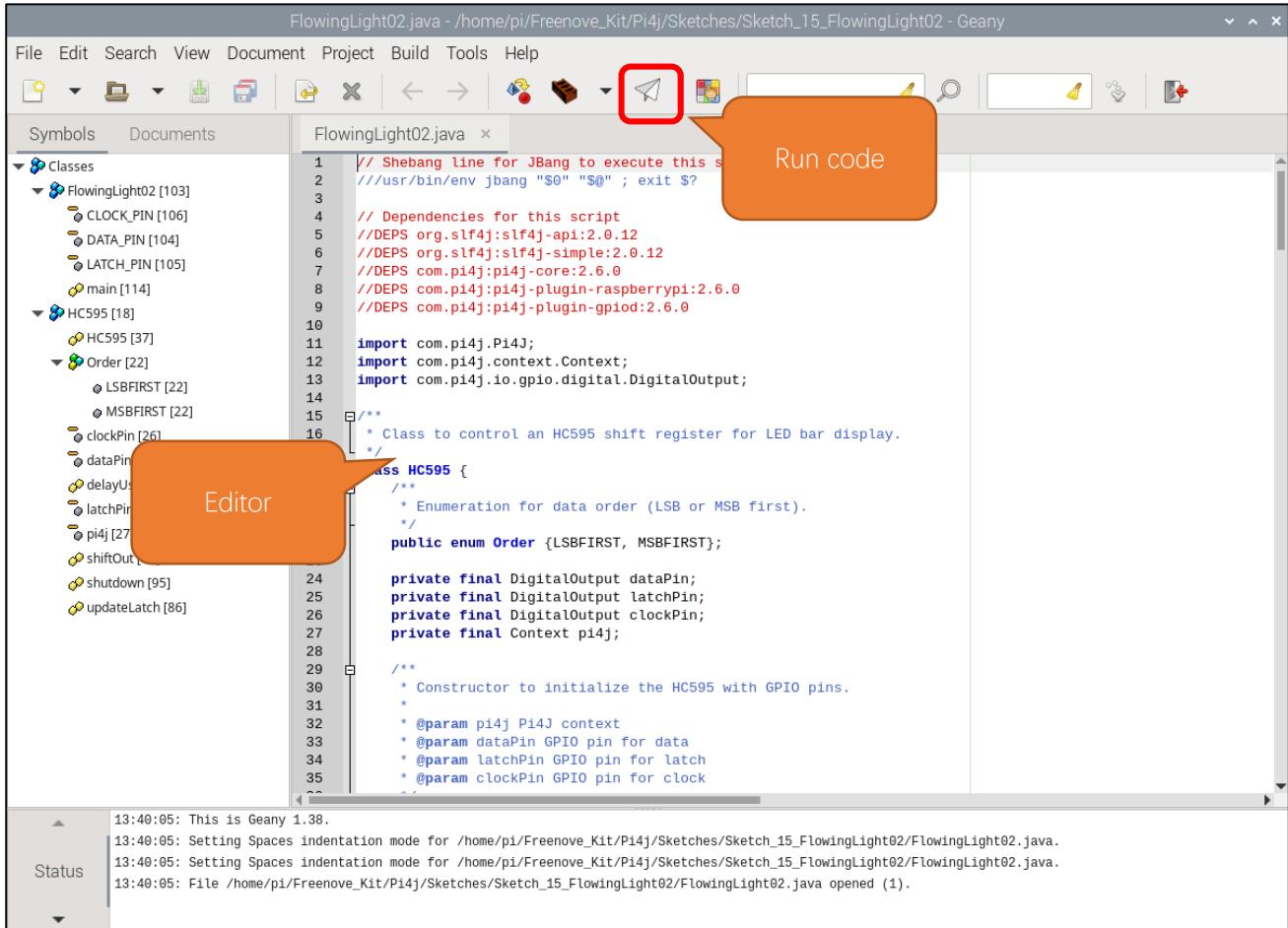
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully initialized.
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_15_FlowingLight02 $
```

You can run the following command to open the code with Geany to view and edit it.

geany FlowingLight02.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //!/usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.gpio.digital.DigitalOutput;
12
13 class HC595 {
14     public enum Order {LSBFIRST, MSBFIRST};
15     private final DigitalOutput dataPin;
```

```
16     private final DigitalOutput latchPin;
17     private final DigitalOutput clockPin;
18     private final Context pi4j;
19
20     public HC595(Context pi4j, int dataPin, int latchPin, int clockPin) {
21         this.pi4j = pi4j;
22         this.dataPin = pi4j.dout().create(dataPin);
23         this.latchPin = pi4j.dout().create(latchPin);
24         this.clockPin = pi4j.dout().create(clockPin);
25     }
26
27     private static void delayUs(long us) {
28         long startTime = System.nanoTime();
29         long endTime = startTime + (us * 1000);
30         while (System.nanoTime() < endTime) {
31             }
32     }
33
34     public void shiftOut(Order order, int val) {
35         int i;
36         for (i = 0; i < 8; i++) {
37             clockPin.low();
38             if (order == Order.LSBFIRST) {
39                 if ((0x01 & (val >> i)) == 0x01) {
40                     dataPin.high();
41                 } else {
42                     dataPin.low();
43                 }
44             } else {
45                 if ((0x80 & (val << i)) == 0x80) {
46                     dataPin.high();
47                 } else {
48                     dataPin.low();
49                 }
50             }
51             clockPin.high();
52         }
53     }
54
55     public void updateLatch() {
56         latchPin.low();
57         delayUs(1);
58         latchPin.high();
59     }
```

```

60
61     public void shutdown() {
62         pi4j.shutdown();
63     }
64 }
65
66 public class FlowingLight02 {
67     private static final int DATA_PIN = 22;
68     private static final int LATCH_PIN = 27;
69     private static final int CLOCK_PIN = 17;
70     public static void main(String[] args) throws Exception {
71         var pi4j = Pi4J.newAutoContext();
72         HC595 ledbar = new HC595(pi4j, DATA_PIN, LATCH_PIN, CLOCK_PIN);
73         try {
74             int x;
75             while (true) {
76                 x = 0x0001;
77                 for (int i = 0; i < 10; i++) {
78                     ledbar.shiftOut(HC595.Order.MSBFIRST, (x >> 8) & 0xff);
79                     ledbar.shiftOut(HC595.Order.MSBFIRST, x & 0xff);
80                     ledbar.updateLatch();
81                     x <<= 1;
82                     Thread.sleep(100);
83                 }
84                 x = 0x0200;
85                 for (int i = 0; i < 10; i++) {
86                     ledbar.shiftOut(HC595.Order.MSBFIRST, (x >> 8) & 0xff);
87                     ledbar.shiftOut(HC595.Order.MSBFIRST, x & 0xff);
88                     ledbar.updateLatch();
89                     x >>= 1;
90                     Thread.sleep(100);
91                 }
92             }
93         } finally {
94             ledbar.shutdown();
95         }
96     }
97 }
```

Define the data transfer order for enumeration types.

	<code>public enum Order {LSBFIRST, MSBFIRST};</code>
--	--

Define the data pin, latch pin, clock pin, and Pi4j context.

```
private final DigitalOutput dataPin;
private final DigitalOutput latchPin;
private final DigitalOutput clockPin;
private final Context pi4j;
```

Constructor, initialize pins and context.

```
public HC595(Context pi4j, int dataPin, int latchPin, int clockPin) {
    this.pi4j = pi4j;
    this.dataPin = pi4j.dout().create(dataPin);
    this.latchPin = pi4j.dout().create(latchPin);
    this.clockPin = pi4j.dout().create(clockPin);
}
```

Delay function in microsecond.

```
private static void delayUs(long us) {
    long startTime = System.nanoTime();
    long endTime = startTime + (us * 1000);
    while (System.nanoTime() < endTime) {
    }
}
```

Shift function for expansion chip. The Raspberry Pi sends data to the extended chip through GPIO.

```
public void shiftOut(Order order, int val) {
    int i;
    for (i = 0; i < 8; i++) {
        clockPin.low();
        if (order == Order.LSBFIRST) {
            if ((0x01 & (val >> i)) == 0x01) {
                dataPin.high();
            } else {
                dataPin.low();
            }
        } else {
            if ((0x80 & (val << i)) == 0x80) {
                dataPin.high();
            } else {
                dataPin.low();
            }
        }
        clockPin.high();
    }
}
```



Update the expansion chip latch to let the expansion chip output the signal. Usually you need to first call the shiftOut function to input data to the expansion chip, and then call the updateLatch function to have the expansion chip output the signal level corresponding to the data.

```
public void updateLatch() {
    latchPin.low();
    delayUs(1);
    latchPin.high();
}
```

When Pi4j context is not used, shut it down to release resources.

```
public void shutdown() {
    pi4j.shutdown();
}
```

Define the pin number of the driver expansion chip.

```
private static final int DATA_PIN = 22;
private static final int LATCH_PIN = 27;
private static final int CLOCK_PIN = 17;
```

Create a pi4j automatic context and create an HC595 instance.

```
var pi4j = Pi4J.newAutoContext();
HC595 ledbar = new HC595(pi4j, DATA_PIN, LATCH_PIN, CLOCK_PIN);
```

The Raspberry Pi controls the LED bar to flow from left to right and then from right to left.

```
while (true) {
    x = 0x0001;
    for (int i = 0; i < 10; i++) {
        ledbar.shiftOut(HC595.Order.MSBFIRST, (x >> 8) & 0xff);
        ledbar.shiftOut(HC595.Order.MSBFIRST, x & 0xff);
        ledbar.updateLatch();
        x <= 1;
        Thread.sleep(100);
    }
    x = 0x0200;
    for (int i = 0; i < 10; i++) {
        ledbar.shiftOut(HC595.Order.MSBFIRST, (x >> 8) & 0xff);
        ledbar.shiftOut(HC595.Order.MSBFIRST, x & 0xff);
        ledbar.updateLatch();
        x >>= 1;
        Thread.sleep(100);
    }
}
```

Shutdown HC595 instance resources.

```
finally {
    ledbar.shutdown();
}
```

# Chapter 16 74HC595 & 4-Digit 7-Segment Display

In this chapter, we will introduce the 7-Segment Display.

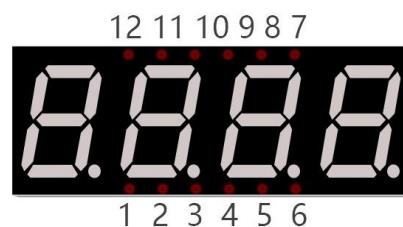
## Project 16.1 4-Digit 7-Segment Display

We will use a 74HC595 IC Chip to control a 4-Digit 7-Segment Display and make it display sixteen decimal characters "0" to "F".

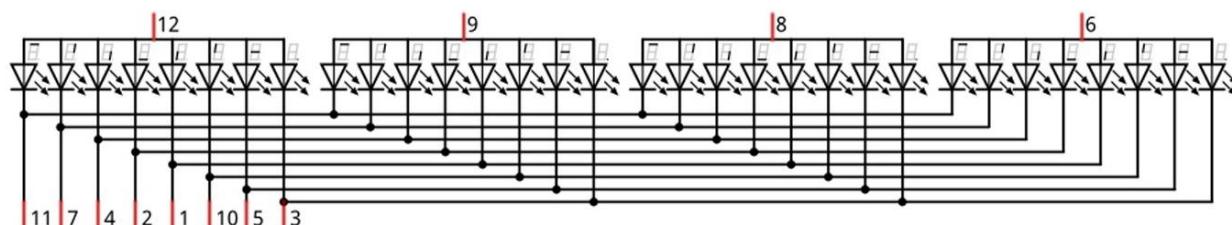
### Component knowledge

#### 4-Digit 7-Segment Display

A 4-Digit 7-segment display integrates four 7-Segment Displays into one module. Therefore, it can display more characters. All of the LEDs contained have a Common Anode and individual Cathodes. Its internal structure and pin designation diagram is shown below:



The internal electronic circuit is shown below, and all 8 LED cathode pins of each 7-Segment Display are connected together.

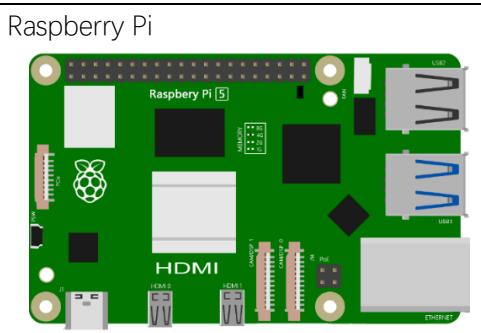
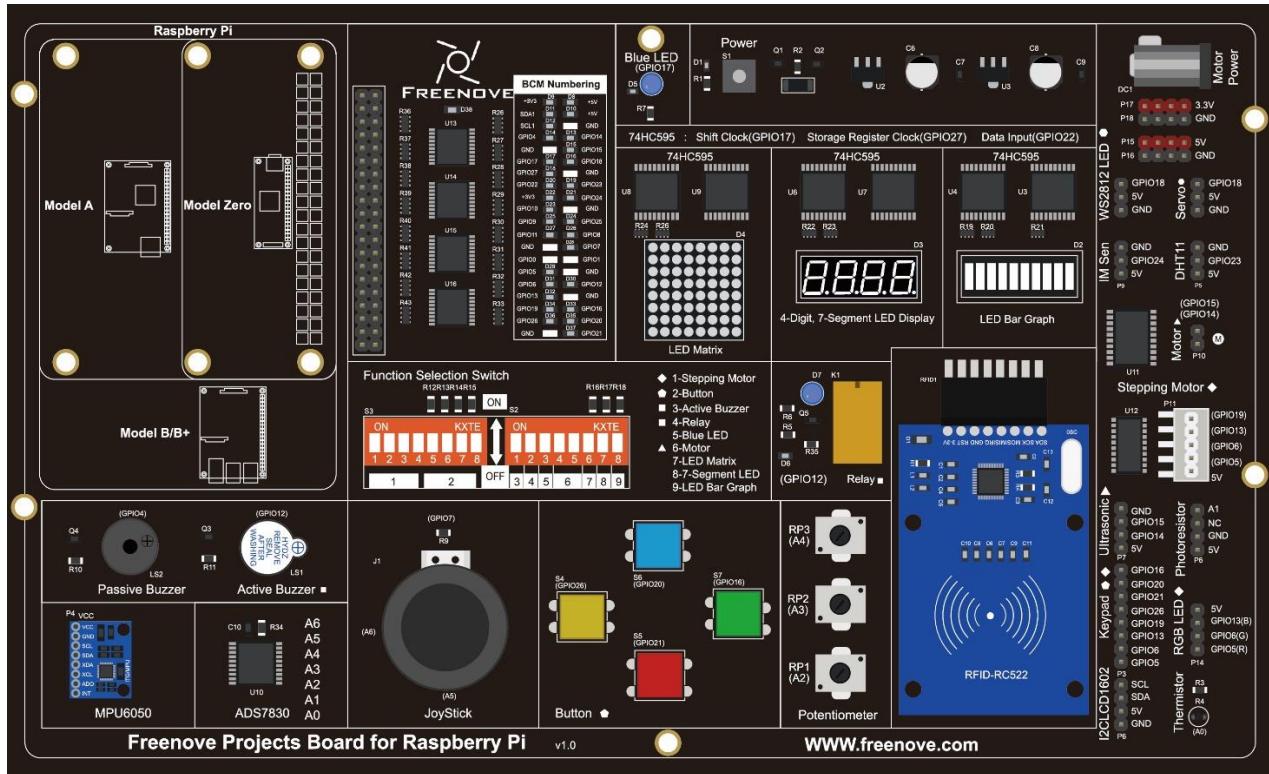


Display method of 4 Digit 7-segment display is similar to 1 Digit 7-segment display. The difference between them is that the 4-Digit displays each Digit is visible in turn, one by one and not together. We need to first send high level to the common end of the first Digit Display, and send low level to the remaining three common ends, and then send content to 8 LED cathode pins of the first Digit Display. At this time, the first 7-Segment Display will show visible content and the remaining three will be OFF.

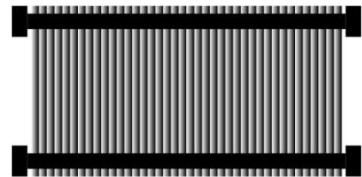
Similarly, the second, third and fourth 7-Segment Displays will show visible content in turn by scanning the display. Although the four number characters are displayed in turn separately, this process is so fast that it is unperceivable to the naked eye. This is due to the principle of optical afterglow effect and the vision persistence effect in human sight. This is how we can see all 4 number characters at the same time. However, if each number character is displayed for a longer period, you will be able to see that the number characters are displayed separately.

## Component List

Freenove Projects Board for Raspberry Pi



GPIO Ribbon Cable

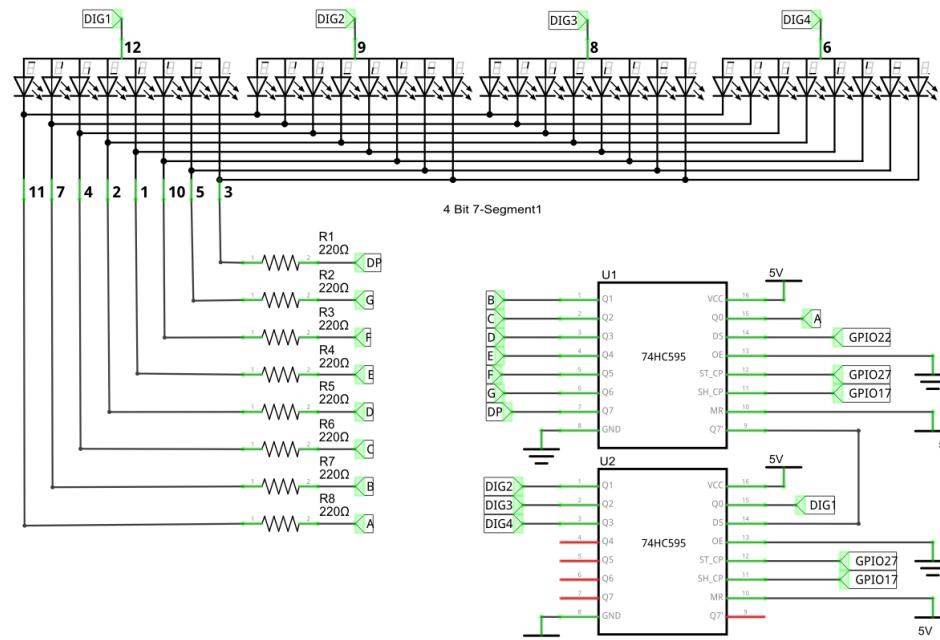


4-Digit 7-Segment Display

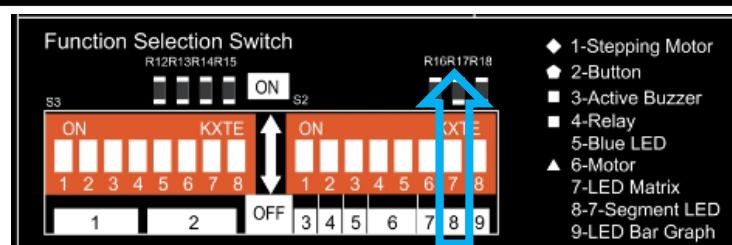
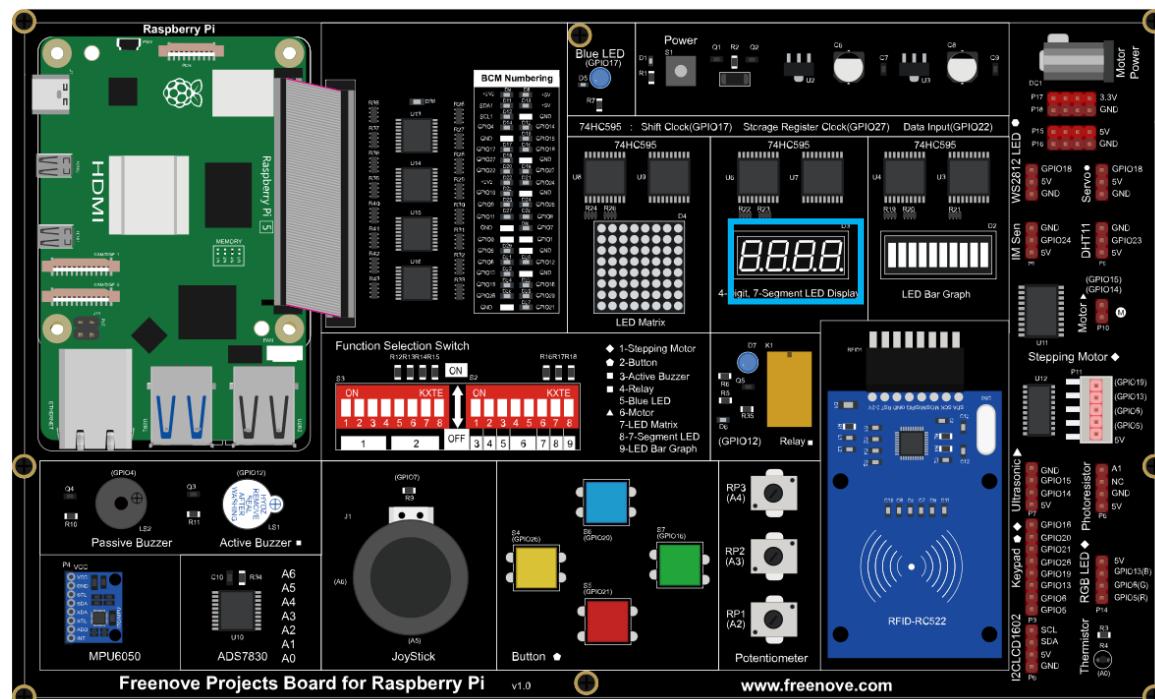


## Circuit

Schematic diagram



Hardware connection.



## Sketch

In this project, we will use the expansion chip to drive a 4-digit 7-segment display.

### Sketch\_16\_1\_SevenSegmentDisplay

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_16_1_SevenSegmentDisplay
```

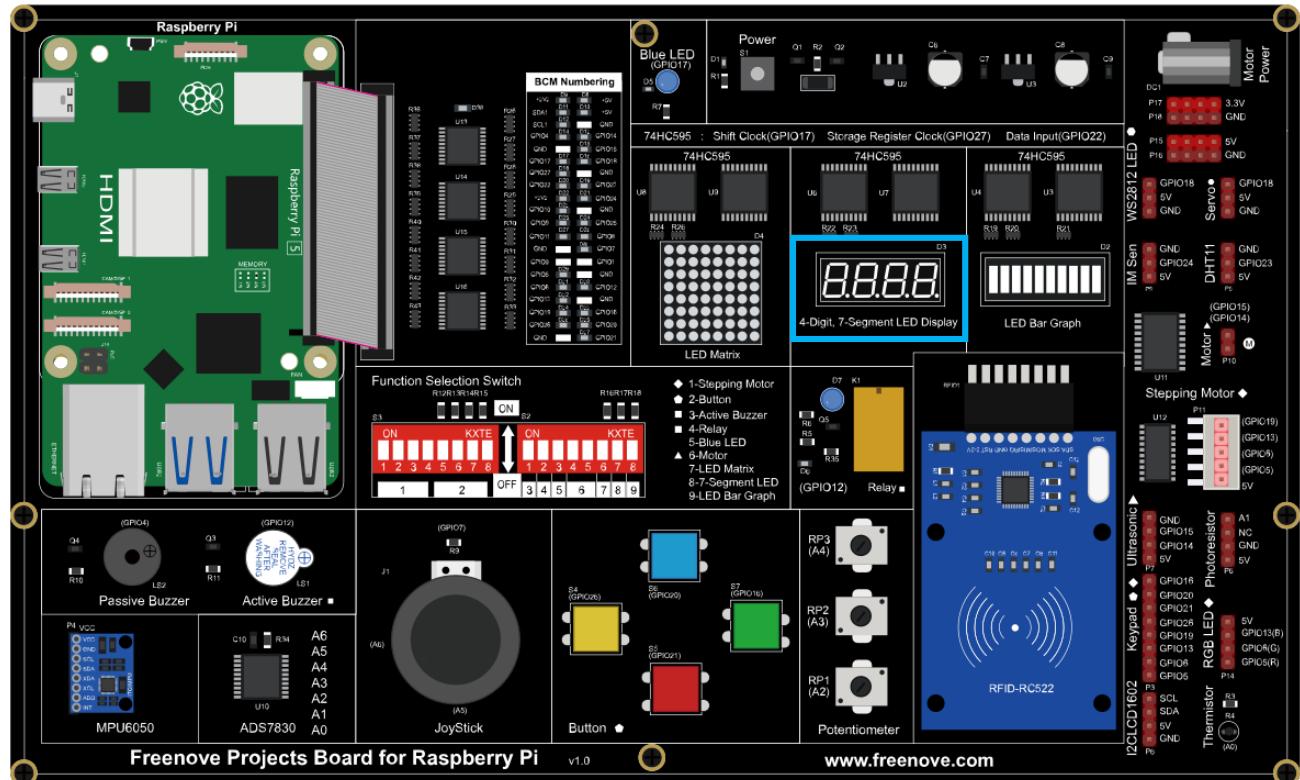
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_16_1_SevenSegmentDisplay
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_16_1_SevenSegmentDisplay $
```

Enter the command to run the code.

```
jbang SevenSegmentDisplay.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_16_1_SevenSegmentDisplay
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_16_1_SevenSegmentDisplay $ jbang SevenSegmentDisplay.java
```

When the code is running, you can see the contents displayed change every 500 milliseconds. The display contents are 0-F.



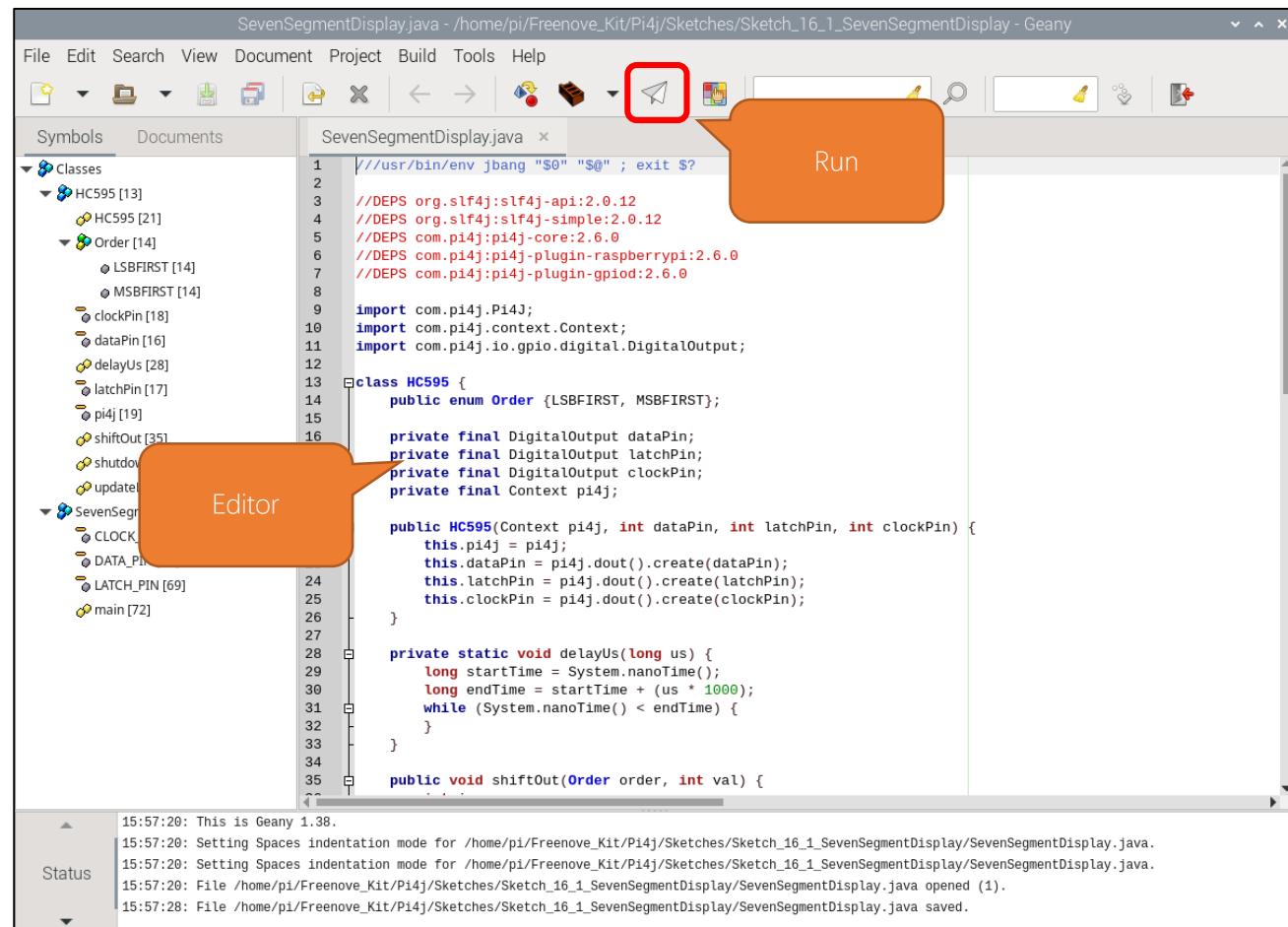
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully initialized.
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_16_1_SevenSegmentDisplay $
```

You can run the following command to open the code with Geany to view and edit it.

**geany SevenSegmentDisplay.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.gpio.digital.DigitalOutput;
12
13 class HC595 {
    .....
}
```

```

65 }
66
67 public class SevenSegmentDisplay {
68     private static final int DATA_PIN = 22;
69     private static final int LATCH_PIN = 27;
70     private static final int CLOCK_PIN = 17;
71
72     public static void main(String[] args) throws Exception {
73         var pi4j = Pi4J.newAutoContext();
74         HC595 segment = new HC595(pi4j, DATA_PIN, LATCH_PIN, CLOCK_PIN);
75
76         try {
77             int[] nums = {0xfffc0, 0xffff9, 0xfffa4, 0xffffb0, 0xffff99, 0xffff92, 0xffff82, 0xffff8,
78                         0xffff80, 0xffff90, 0xffff88, 0xffff83, 0xffffc6, 0xffffa1, 0xffff86, 0xffff8e};
79
80             while (true) {
81                 for (int num : nums) {
82                     // Shift out the high byte (dummy in this case)
83                     segment.shiftOut(HC595.Order.MSBFIRST, (num >> 8) & 0xff);
84                     // Shift out the low byte containing the actual digit
85                     segment.shiftOut(HC595.Order.MSBFIRST, num & 0xff);
86                     segment.updateLatch();
87                     Thread.sleep(500); // Delay before changing the next digit
88                 }
89             } finally {
90                 segment.shutdown();
91             }
92         }
93     }

```

Define an array to control the display content of the digital tube.

	<code>int[] nums = {0xfffc0, 0xffff9, 0xfffa4, 0xffffb0, 0xffff99, 0xffff92, 0xffff82, 0xffff8, 0xffff80, 0xffff90, 0xffff88, 0xffff83, 0xffffc6, 0xffffa1, 0xffff86, 0xffff8e};</code>
--	---

In the given circuit, the 74HC595 shift registers are used to control a digital tube display. The common anodes of the digital tube are controlled by the outputs Q3 to Q0 of chip U2, while the common cathodes are controlled by Q7 to Q0 of chip U1. To display '0000' on the digital tube, the following steps are necessary:

1. Set all the common anode pins (controlled by U2) to a high level to ensure they are all active.
2. Set the common cathode pins that correspond to the segments that need to be lit (segments for '0') to a low level, and those that need to be off to a high level.
3. Since the two 74HC595s are cascaded, the data for chip U2 (which controls the anodes) must be sent first, followed by the data for chip U1 (which controls the cathodes).

This sequence ensures that the digital tube will display '0000' with the correct segments illuminated.

	<code>segment.shiftOut(HC595.Order.MSBFIRST, (num &gt;&gt; 8) &amp; 0xff); segment.shiftOut(HC595.Order.MSBFIRST, num &amp; 0xff);</code>
--	---

Update the register to have the two chips output signals to control the display content of the digital tube.

```
segment.updateLatch();
```

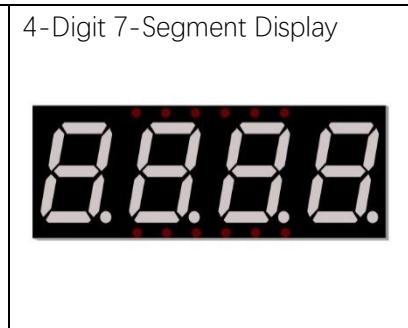
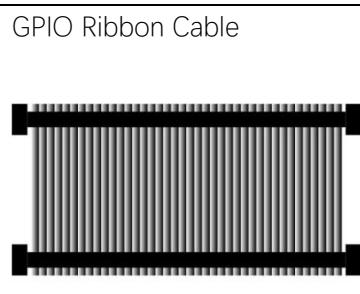
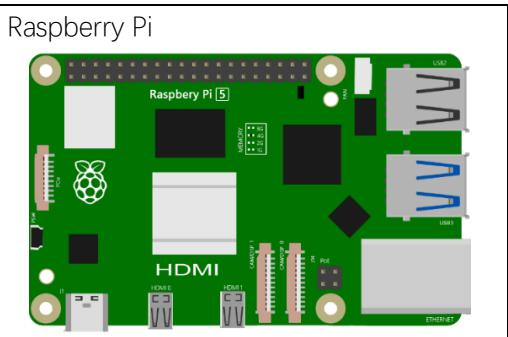
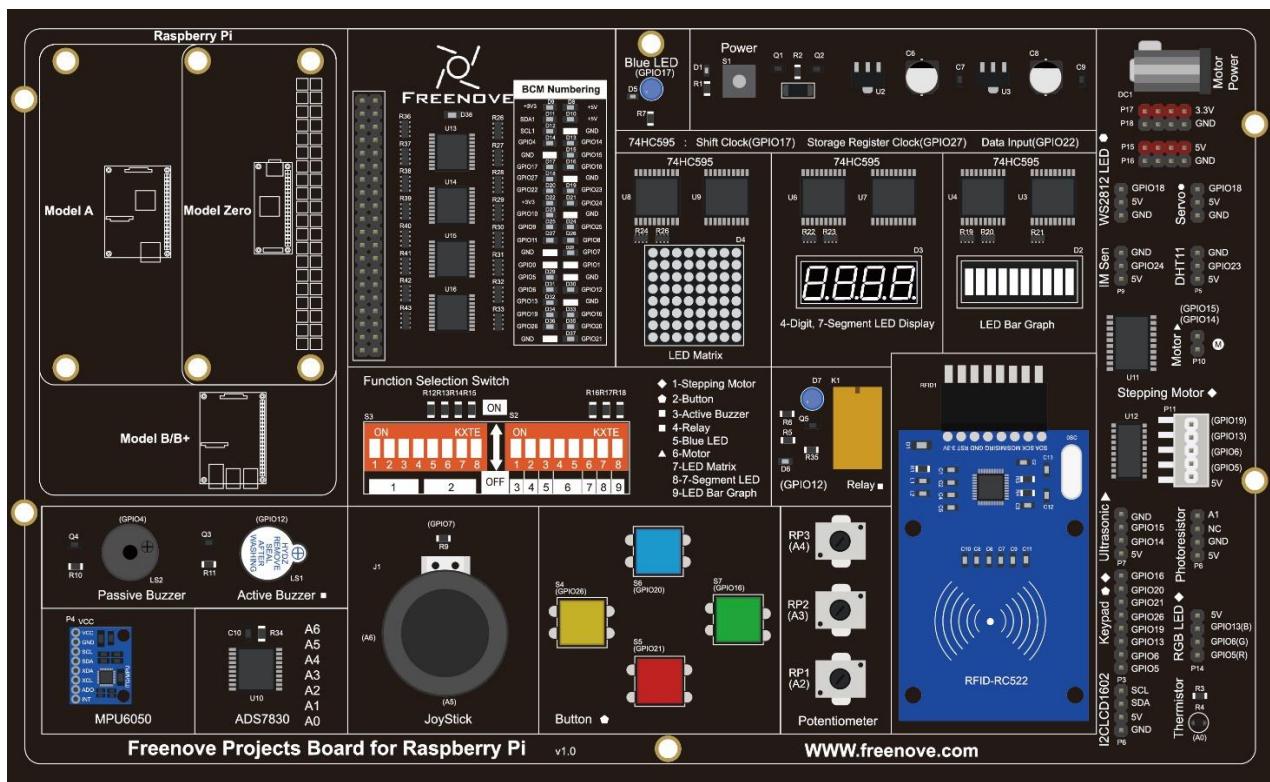
The digital tube displays from 0 to F in sequence, with a time interval of 500 milliseconds.

```
while (true) {  
    for (int num : nums) {  
        // Shift out the high byte (dummy in this case)  
        segment.shiftOut(HC595.Order.MSBFIRST, (num >> 8) & 0xff);  
        // Shift out the low byte containing the actual digit  
        segment.shiftOut(HC595.Order.MSBFIRST, num & 0xff);  
        segment.updateLatch();  
        Thread.sleep(500); // Delay before changing the next digit  
    }  
}
```

## Project 16.2 4-Digit 7-Segment Display

### Component List

Freenove Projects Board for Raspberry Pi



### Circuit

The same as that of 16.1

If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this project, we will use the expansion chip to drive the 4-digit digital tube to display different contents.

### Sketch\_16\_2\_StopWatch

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_16_2_StopWatch
```

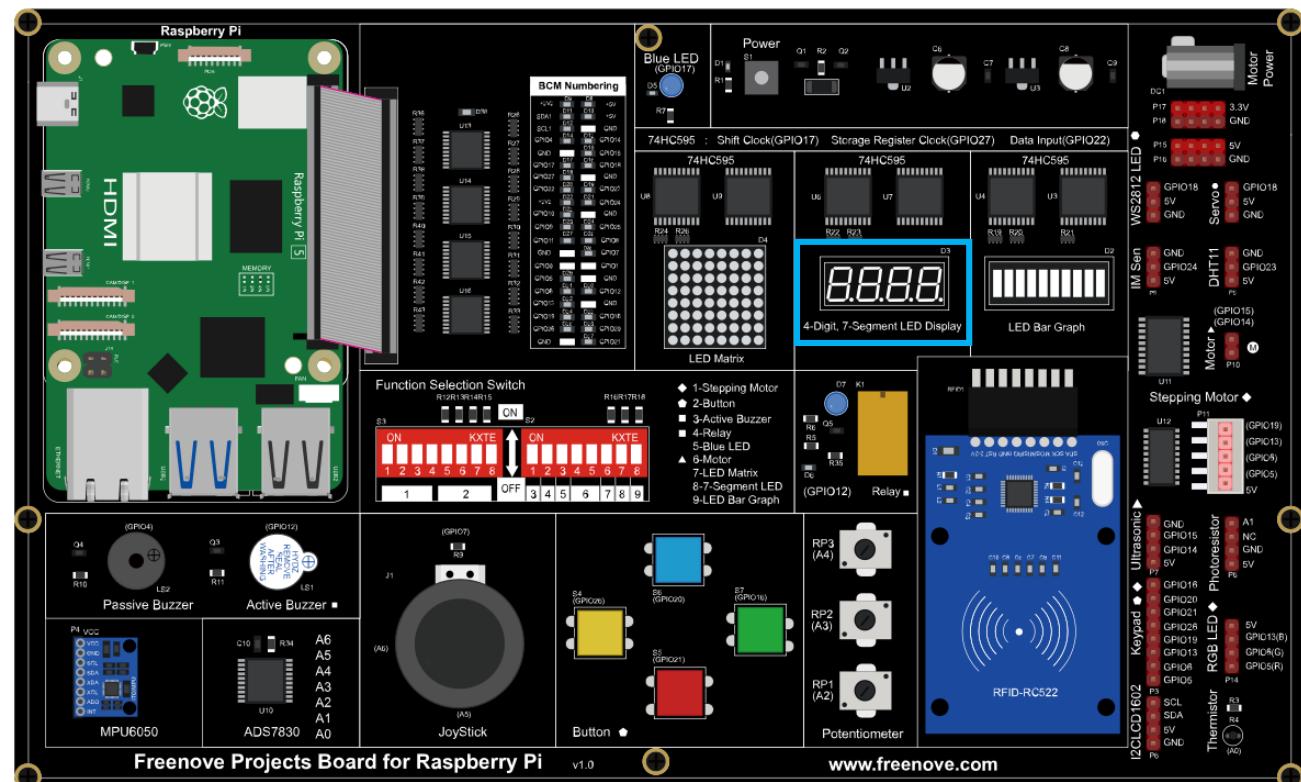
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_16_2_StopWatch
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_16_2_StopWatch $
```

Enter the command to run the code.

```
jbang Stopwatch.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_16_2_StopWatch
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_16_2_StopWatch $ jbang Stopwatch.java
```

When the code is running, you can see the digital tube displays numbers from 0000 to 9999, and the process repeats.



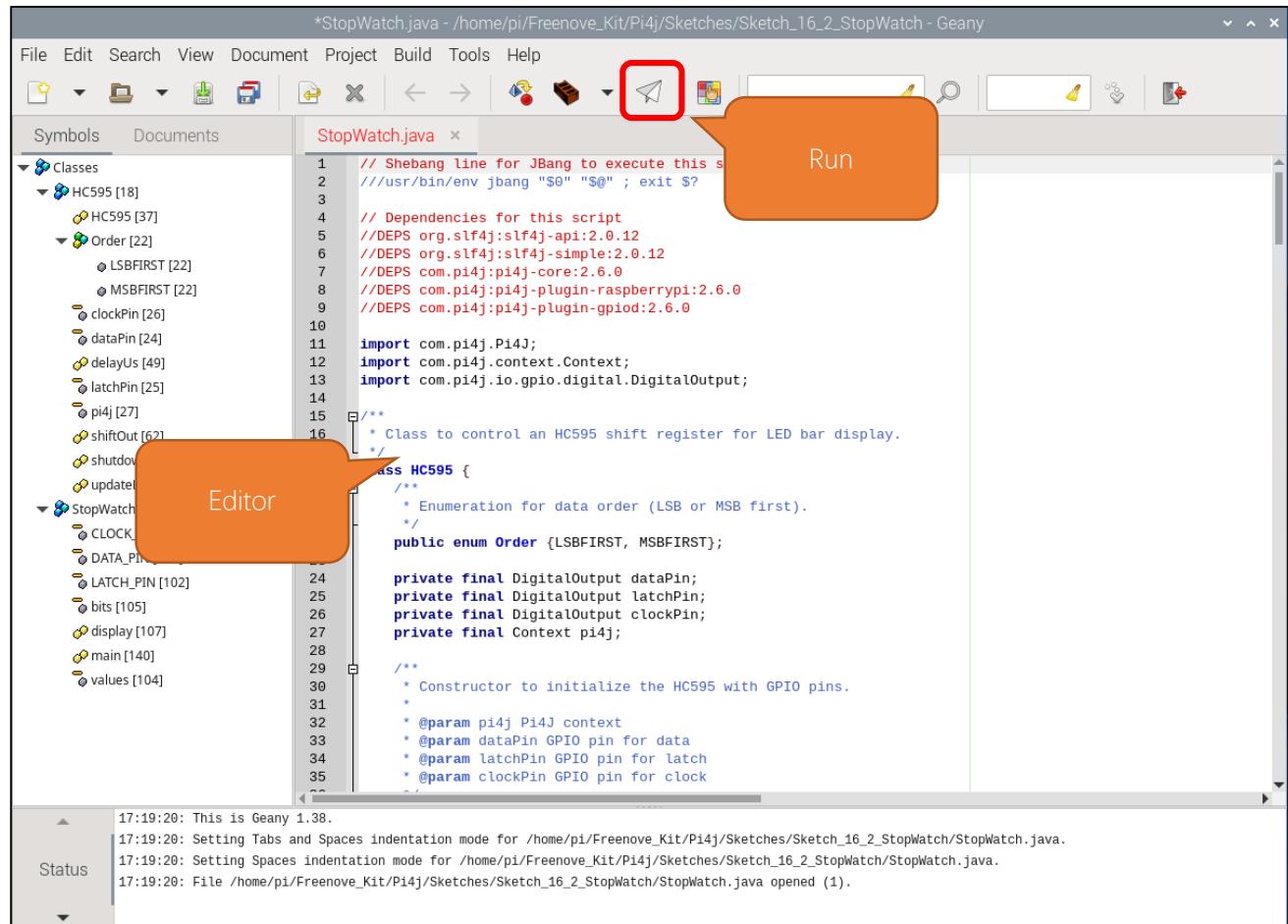
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully initialized.
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_16_1_SevenSegmentDisplay $
```

You can run the following command to open the code with Geany to view and edit it.

**geany StopWatch.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //!/usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.gpio.digital.DigitalOutput;
12
13 class HC595 {
    .....

```

```
64    }
65
66    public class StopWatch {
67        private static final int DATA_PIN = 22;
68        private static final int LATCH_PIN = 27;
69        private static final int CLOCK_PIN = 17;
70        private static final int[] values = {0xc0, 0xf9, 0xa4, 0xb0, 0x99, 0x92, 0x82, 0xf8,
71                                         0x80, 0x90, 0x88, 0x83, 0xc6, 0xa1, 0x86, 0x8e};
72        private static final int[] bits = {0x01, 0x02, 0x04, 0x08};
73
74        public static void display(HC595 segment, int dec, int times) {
75            int thousand_bit = (int)dec%10000/1000;
76            int hundred_bit = (int)dec%1000/100;
77            int ten_bit      = (int)dec%100/10;
78            int units_bit    = (int)dec%10;
79            try {
80                for(int i=0; i<times; i++) {
81                    segment.shiftOut(HC595.Order.MSBFIRST, bits[0] & 0xff);
82                    segment.shiftOut(HC595.Order.MSBFIRST, values[thousand_bit] & 0xff);
83                    segment.updateLatch();
84                    Thread.sleep(1);
85
86                    segment.shiftOut(HC595.Order.MSBFIRST, bits[1] & 0xff);
87                    segment.shiftOut(HC595.Order.MSBFIRST, values[hundred_bit] & 0xff);
88                    segment.updateLatch();
89                    Thread.sleep(1);
90
91                    segment.shiftOut(HC595.Order.MSBFIRST, bits[2] & 0xff);
92                    segment.shiftOut(HC595.Order.MSBFIRST, values[ten_bit] & 0xff);
93                    segment.updateLatch();
94                    Thread.sleep(1);
95
96                    segment.shiftOut(HC595.Order.MSBFIRST, bits[3] & 0xff);
97                    segment.shiftOut(HC595.Order.MSBFIRST, values[units_bit] & 0xff);
98                    segment.updateLatch();
99                    Thread.sleep(1);
100                }
101            } catch (InterruptedException e) {
102                Thread.currentThread().interrupt();
103            }
104        }
105        public static void main(String[] args) throws Exception {
106            var pi4j = Pi4J.newAutoContext();
```

```

107     HC595 segment = new HC595(pi4j, DATA_PIN, LATCH_PIN, CLOCK_PIN);
108
109     try {
110         while (true) {
111             for (int i=0; i<9999; i++) {
112                 display(segment, i, 100);
113             }
114         }
115     } finally {
116         segment.shutdown();
117     }
118 }
119 }
```

Define an array called 'values' to store the content displayed on the digital tube. Define an array called 'bits' to store the control bits for the common anode of the digital tube.

```

private static final int[] values = {0xc0, 0xf9, 0xa4, 0xb0, 0x99, 0x92, 0x82, 0xf8,
                                    0x80, 0x90, 0x88, 0x83, 0xc6, 0xa1, 0x86, 0x8e};
private static final int[] bits   = {0x01, 0x02, 0x04, 0x08};
```

Extract the values for the thousands, hundreds, tens, and ones places from the 'dec' variable.

```

int thousand_bit = (int)dec%10000/1000;
int hundred_bit = (int)dec%1000/100;
int ten_bit      = (int)dec%100/10;
int units_bit    = (int)dec%10;
```

To display the number 1234 on a digital tube, we must first break down the number into its individual digits: 1, 2, 3, and 4.

We then proceed to control the digital tube to show the digit 1 in the first position for 1 millisecond, followed by the digit 2 in the second position for another millisecond, and continue this pattern for digits 3 and 4.

After displaying each digit sequentially, we repeat the entire sequence `times` times. Due to the rapid cycling through the digits, the human eye perceives a continuous display of the number 1234 on the digital tube.

```

for(int i=0; i<times; i++){
    segment.shiftOut(HC595.Order.MSBFIRST, bits[0] & 0xff);
    segment.shiftOut(HC595.Order.MSBFIRST, values & 0xff);
    segment.updateLatch();
    Thread.sleep(1);

    segment.shiftOut(HC595.Order.MSBFIRST, bits[1] & 0xff);
    segment.shiftOut(HC595.Order.MSBFIRST, values[hundred_bit] & 0xff);
    segment.updateLatch();
    Thread.sleep(1);

    segment.shiftOut(HC595.Order.MSBFIRST, bits[2] & 0xff);
    segment.shiftOut(HC595.Order.MSBFIRST, values[ten_bit] & 0xff);
    segment.updateLatch();
```

```
    Thread.sleep(1);  
    segment.shiftOut(HC595.Order.MSBFIRST, bits[3] & 0xff);  
    segment.shiftOut(HC595.Order.MSBFIRST, values[units_bit] & 0xff);  
    segment.updateLatch();  
    Thread.sleep(1);  
}
```

Call the 'display' function to cycle through the display on the digital tube, showing numbers from 0000 to 9999. The time interval between two consecutive calls to 'display' is 100(times) \* 4(bits) \* 1ms = 400 milliseconds.

```
while (true) {  
    for (int i=0; i<9999; i++) {  
        display(segment, i, 100);  
    }  
}
```



# Chapter 17 74HC595 & LED Matrix

Thus far, we have learned how to use the 74HC595 IC Chip to control the Bar Graph LED and the 7-Segment Display. We will now use 74HC595 IC Chips to control an LED Matrix.

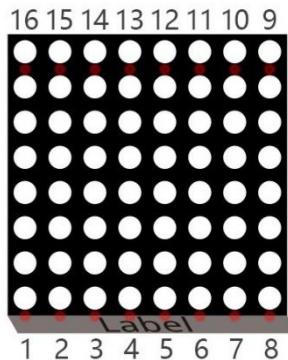
## Project 17.1 LED Matrix

In this project, we will use two 74HC595 IC chips to control a monochrome (one color) (8X8) LED Matrix to make it display both simple graphics and characters.

### Component knowledge

#### LED matrix

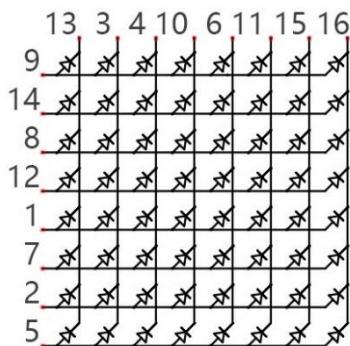
An LED Matrix is a rectangular display module that consists of a uniform grid of LEDs. The following is an 8X8 monochrome (one color) LED Matrix containing 64 LEDs (8 rows by 8 columns).



In order to facilitate the operation and reduce the number of ports required to drive this component, the Positive Poles of the LEDs in each row and Negative Poles of the LEDs in each column are respectively connected together inside the LED Matrix module, which is called a Common Anode. There is another arrangement type. Negative Poles of the LEDs in each row and the Positive Poles of the LEDs in each column are respectively connected together, which is called a Common Cathode.

The LED Matrix that we use in this project is a Common Anode LED Matrix.

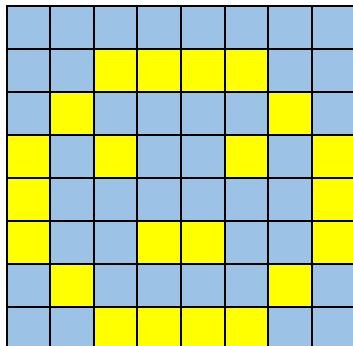
Connection mode of Common Anode



Connection mode of Common Cathode



Here is how a Common Anode LED Matrix works. First, choose 16 ports on RPi board to connect to the 16 ports of LED Matrix. Configure one port in columns for low level, which makes that column the selected port. Then configure the eight port in the row to display content in the selected column. Add a delay value and then select the next column that outputs the corresponding content. This kind of operation by column is called Scan. If you want to display the following image of a smiling face, you can display it in 8 columns, and each column is represented by one byte.



1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0
0	0	1	1	1	1	0	0
0	1	0	0	0	0	1	0
1	0	1	0	0	1	0	1
1	0	0	0	0	0	0	1
1	0	0	1	1	0	0	1
0	1	0	0	0	0	1	0
0	0	1	1	1	1	0	0

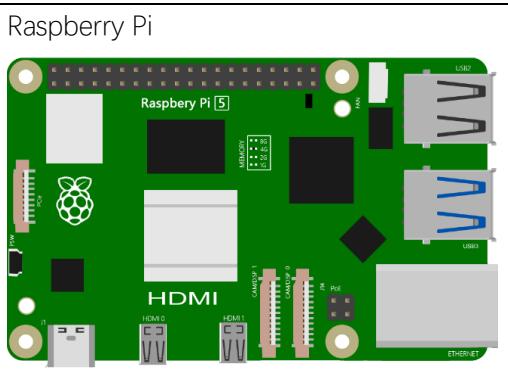
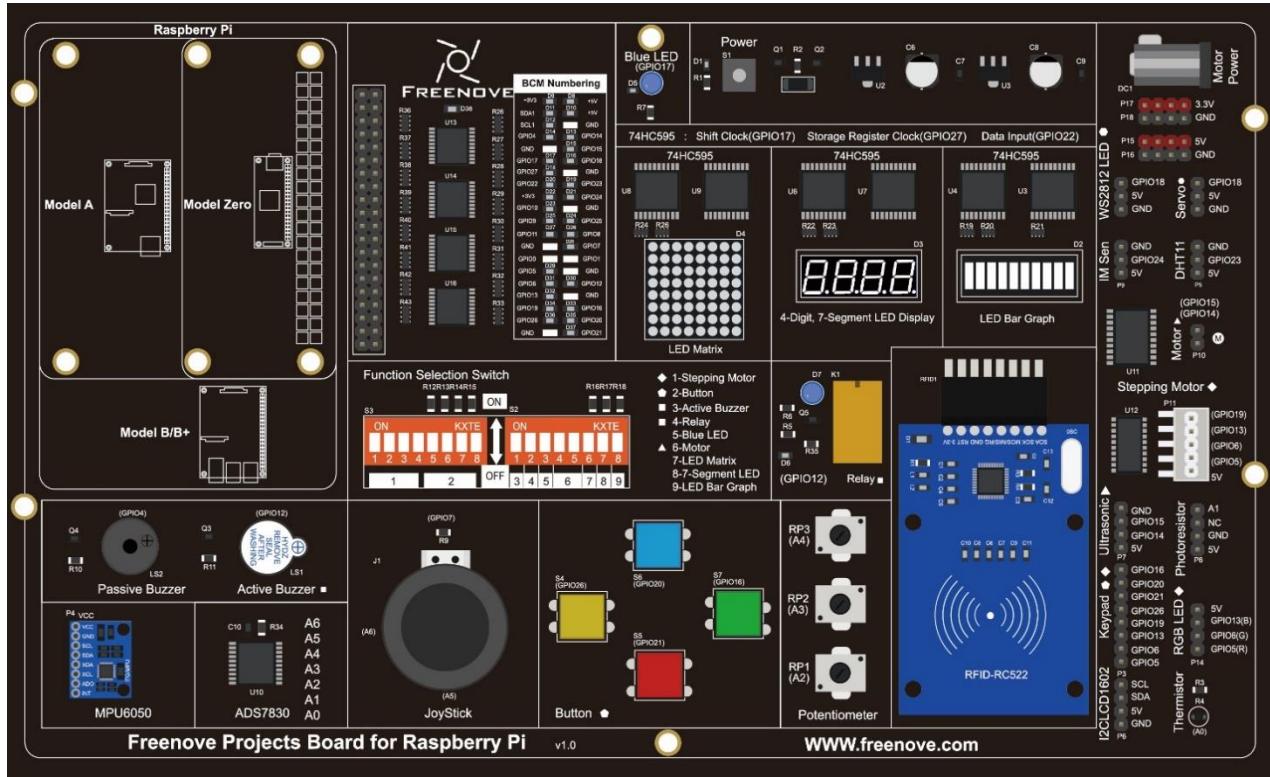
Column	Binary	Hexadecimal
1	0001 1100	0x1c
2	0010 0010	0x22
3	0101 0001	0x51
4	0100 0101	0x45
5	0100 0101	0x45
6	0101 0001	0x51
7	0010 0010	0x22
8	0001 1100	0x1c

To begin, display the first column, then turn off the first column and display the second column. (and so on) .... turn off the seventh column and display the 8th column, and then start the process over from the first column again like the control of LED Bar Graph project. The whole process will be repeated rapidly in a loop. Due to the principle of optical afterglow effect and the vision persistence effect in human sight, we will see a picture of a smiling face directly rather than individual columns of LEDs turned ON one column at a time (although in fact this is the reality we cannot perceive).

Scanning rows is another option to display on an LED Matrix (dot matrix grid). Whether scanning by row or column, 16 GPIO is required. In order to save GPIO ports of control board, two 74HC595 IC Chips are used in the circuit. Every 74HC595 IC Chip has eight parallel output ports, so two of these have a combined total of 16 ports, which is just enough for our project. The control lines and data lines of the two 74HC595 IC Chips are not all connected to the RPi, but connect to the Q7 pin of first stage 74HC595 IC Chip and to the data pin of second IC Chip. The two 74HC595 IC Chips are connected in series, which is the same as using one "74HC595 IC Chip" with 16 parallel output ports.

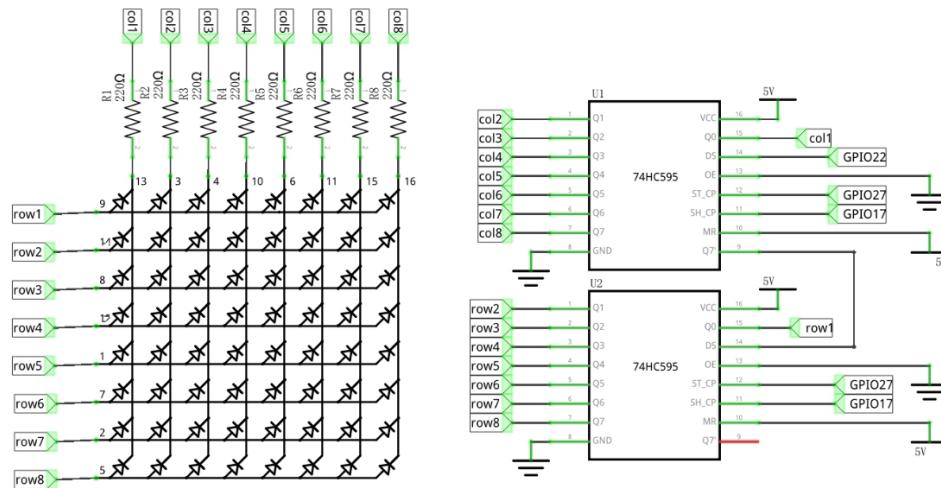
## Component List

Freenove Projects Board for Raspberry Pi x1



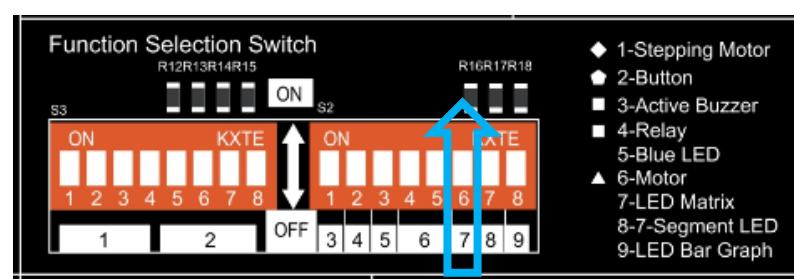
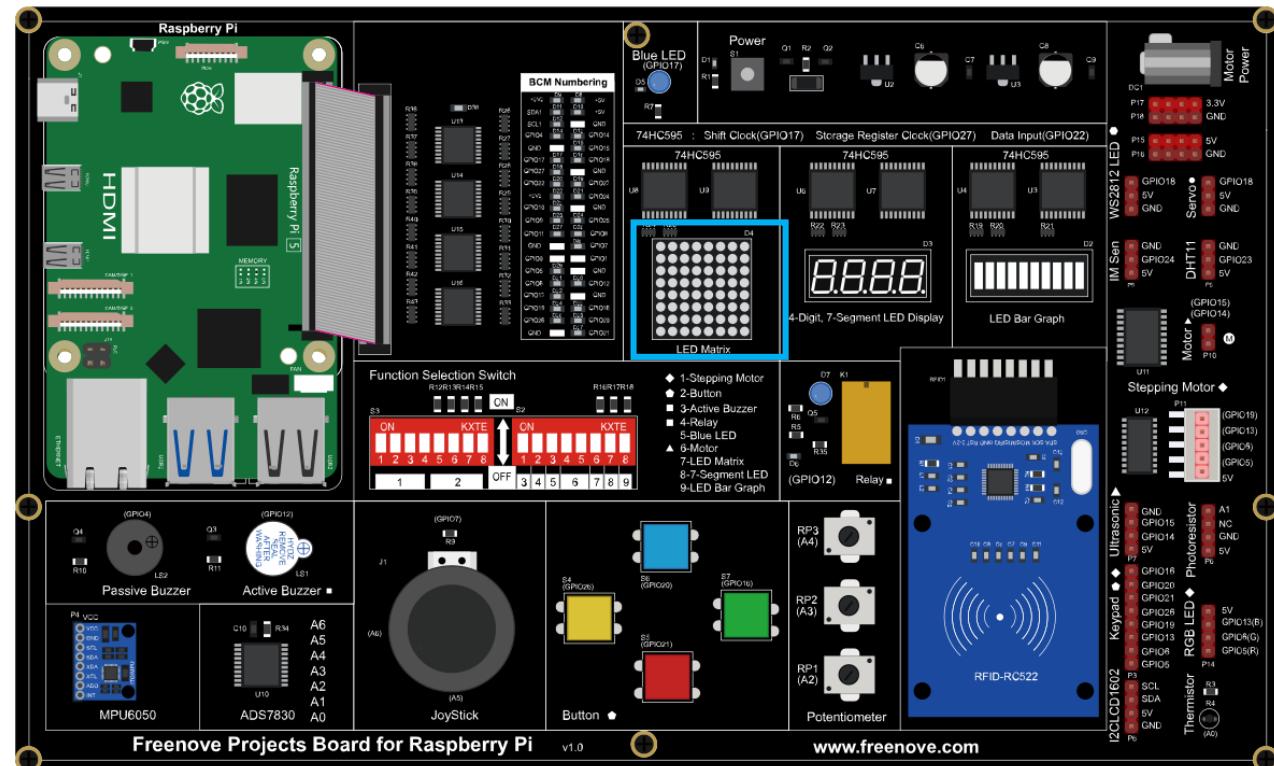
## Circuit

Schematic diagram



Hardware connection.

If it doesn't work, rotate the LED matrix for 180°.



## Sketch

In this project, we will drive the LED matrix to display different contents.

### Sketch\_17\_LEDMatrix

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_17_LEDMatrix
```

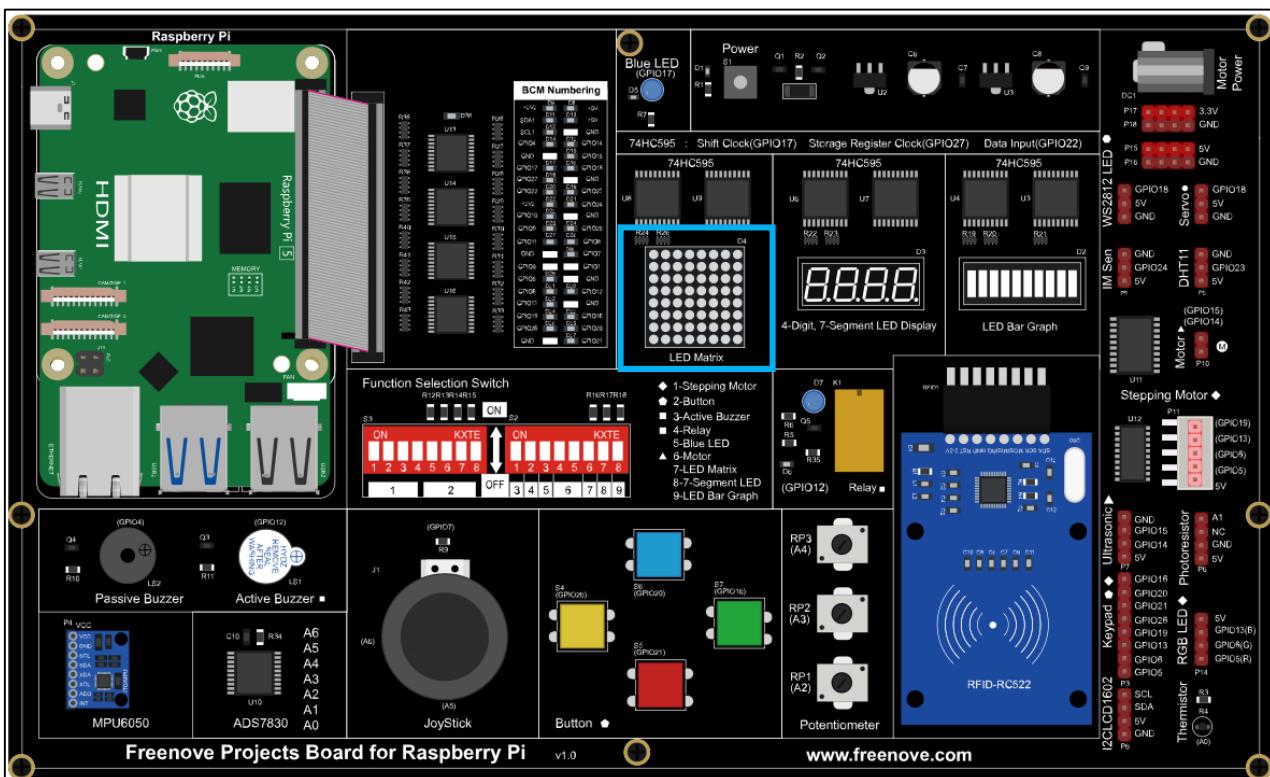
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_17_LEDMatrix
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_17_LEDMatrix $
```

Enter the command to run the code.

```
jbang LEDMatrix.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_17_LEDMatrix
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_17_LEDMatrix $ jbang LEDMatrix.java
```

When the code is running, you can see that the LED matrix first displays a smiley face, then scrolls through the characters 0-F, and repeats this process in a continuous loop.



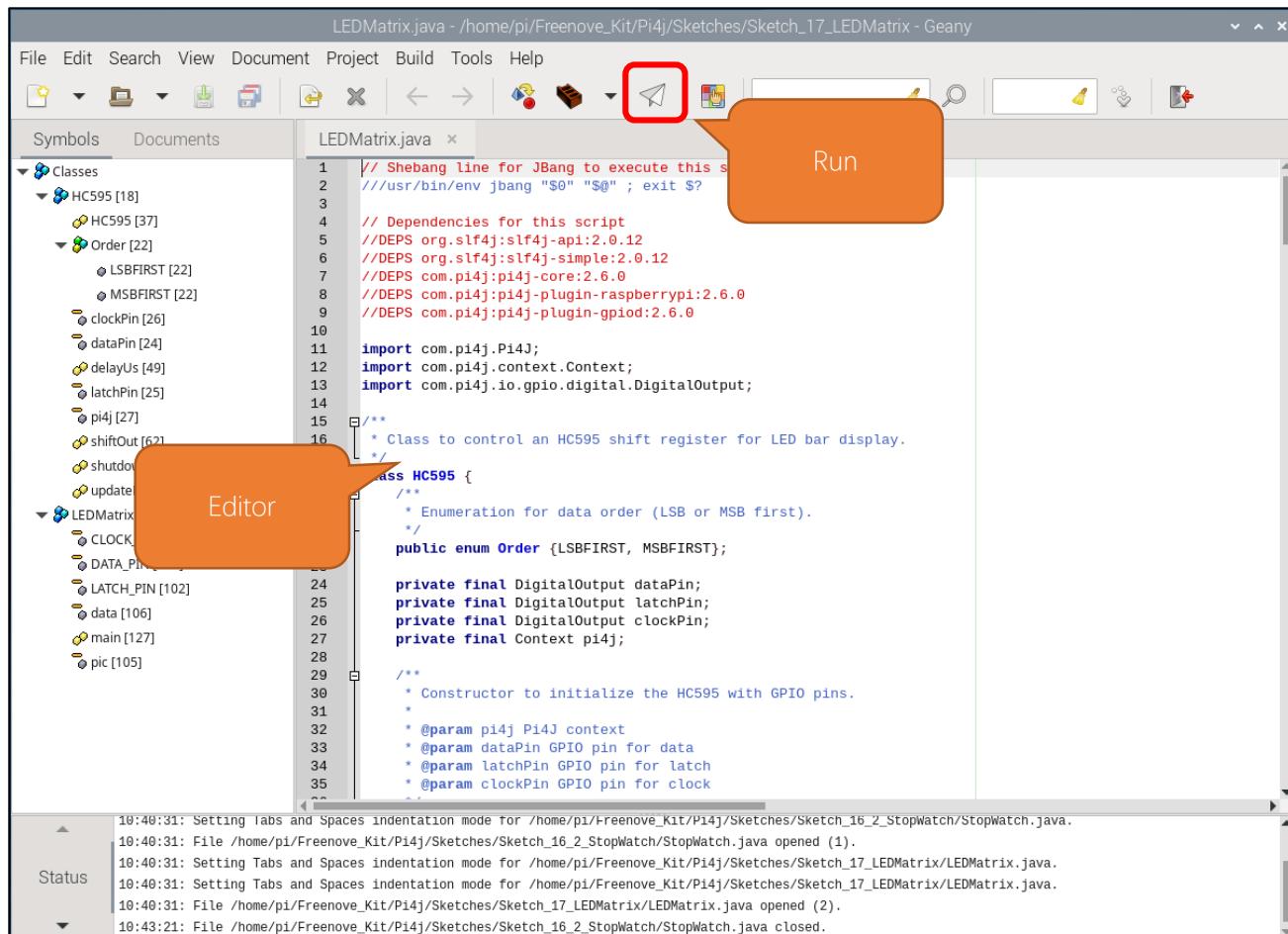
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.library.gpiod.internal.GpioDContext - Using chip gpiochip4 pinctrl-rpi
[main] INFO com.pi4j.platform.impl.DefaultRuntimePlatforms - adding platform to managed platform map [id=raspberrypi; name=RaspberryPi Platform; priority=5; class=com.pi4j.plugin.raspberrypi.platform.RaspberryPiPlatform]
[main] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully initialized.
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_17_LEDMatrix $
```

You can run the following command to open the code with Geany to view and edit it.

### geany LEDMatrix.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //!/usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.context.Context;
11 import com.pi4j.io.gpio.digital.DigitalOutput;
12
13 class HC595 {
14     .....
15 }

```

```
65
66 public class LEDMatrix {
67     private static final int DATA_PIN = 22;
68     private static final int LATCH_PIN = 27;
69     private static final int CLOCK_PIN = 17;
70
71     private static final int[] pic = {0x1c, 0x22, 0x51, 0x45, 0x45, 0x51, 0x22, 0x1c};
72     private static final int[] data = { // data of "0-F"
73         0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, // ""
74         0x00, 0x00, 0x3E, 0x41, 0x41, 0x3E, 0x00, 0x00, // "0"
75         0x00, 0x00, 0x21, 0x7F, 0x01, 0x00, 0x00, 0x00, // "1"
76         0x00, 0x00, 0x23, 0x45, 0x49, 0x31, 0x00, 0x00, // "2"
77         0x00, 0x00, 0x22, 0x49, 0x49, 0x36, 0x00, 0x00, // "3"
78         0x00, 0x00, 0x0E, 0x32, 0x7F, 0x02, 0x00, 0x00, // "4"
79         0x00, 0x00, 0x79, 0x49, 0x49, 0x46, 0x00, 0x00, // "5"
80         0x00, 0x00, 0x3E, 0x49, 0x49, 0x26, 0x00, 0x00, // "6"
81         0x00, 0x00, 0x60, 0x47, 0x48, 0x70, 0x00, 0x00, // "7"
82         0x00, 0x00, 0x36, 0x49, 0x49, 0x36, 0x00, 0x00, // "8"
83         0x00, 0x00, 0x32, 0x49, 0x49, 0x3E, 0x00, 0x00, // "9"
84         0x00, 0x00, 0x3F, 0x44, 0x44, 0x3F, 0x00, 0x00, // "A"
85         0x00, 0x00, 0x7F, 0x49, 0x49, 0x36, 0x00, 0x00, // "B"
86         0x00, 0x00, 0x3E, 0x41, 0x41, 0x22, 0x00, 0x00, // "C"
87         0x00, 0x00, 0x7F, 0x41, 0x41, 0x3E, 0x00, 0x00, // "D"
88         0x00, 0x00, 0x7F, 0x49, 0x49, 0x41, 0x00, 0x00, // "E"
89         0x00, 0x00, 0x7F, 0x48, 0x48, 0x40, 0x00, 0x00, // "F"
90         0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, // ""
91     };
92
93     public static void main(String[] args) throws Exception {
94         var pi4j = Pi4J.newAutoContext();
95         HC595 ledMatrix = new HC595(pi4j, DATA_PIN, LATCH_PIN, CLOCK_PIN);
96
97         try {
98             while(true){
99                 for(int j=0; j<500; j++){ //Repeat enough times to display the smiling face a
100                     period of time
101                     int x = 0x80;
102                     for(int i=0; i<8; i++){
103                         ledMatrix.shiftOut(HC595.Order.MSBFIRST, pic[i] & 0xff);
104                         ledMatrix.shiftOut(HC595.Order.MSBFIRST, ~x);
105                         ledMatrix.updateLatch();
106                         x >>= 1; //display the next column
107                         Thread.sleep(1);
108                     }
109                 }
110             }
111         }
112     }
113 }
```

```

107         }
108         for(int k=0; k<data.length-8; k++) { //sizeof(data) total number of "0-F"
109             columns
110             for(int j=0; j<10; j++) {
111                 int x=0x80;
112                 for(int i=k; i<8+k; i++) {
113                     ledMatrix.shiftOut(HC595.Order.MSBFIRST, data[i] & 0xff);
114                     ledMatrix.shiftOut(HC595.Order.MSBFIRST, ~x);
115                     ledMatrix.updateLatch();
116                     x >>= 1;
117                     Thread.sleep(1);
118                 }
119             }
120         }
121     } catch (InterruptedException e) {
122         Thread.currentThread().interrupt();
123     } finally {
124         ledMatrix.shutdown();
125     }
126 }
127 }
```

Define the contents displayed on the LED matrix.

```

private static final int[] pic = {0x1c, 0x22, 0x51, 0x45, 0x45, 0x51, 0x22, 0x1c};
private static final int[] data = { // data of "0-F"
    0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, // ""
    0x00, 0x00, 0x3E, 0x41, 0x41, 0x3E, 0x00, 0x00, // "0"
    0x00, 0x00, 0x21, 0x7F, 0x01, 0x00, 0x00, 0x00, // "1"
    0x00, 0x00, 0x23, 0x45, 0x49, 0x31, 0x00, 0x00, // "2"
    0x00, 0x00, 0x22, 0x49, 0x49, 0x36, 0x00, 0x00, // "3"
    0x00, 0x00, 0x0E, 0x32, 0x7F, 0x02, 0x00, 0x00, // "4"
    0x00, 0x00, 0x79, 0x49, 0x49, 0x46, 0x00, 0x00, // "5"
    0x00, 0x00, 0x3E, 0x49, 0x49, 0x26, 0x00, 0x00, // "6"
    0x00, 0x00, 0x60, 0x47, 0x48, 0x70, 0x00, 0x00, // "7"
    0x00, 0x00, 0x36, 0x49, 0x49, 0x36, 0x00, 0x00, // "8"
    0x00, 0x00, 0x32, 0x49, 0x49, 0x3E, 0x00, 0x00, // "9"
    0x00, 0x00, 0x3F, 0x44, 0x44, 0x3F, 0x00, 0x00, // "A"
    0x00, 0x00, 0x7F, 0x49, 0x49, 0x36, 0x00, 0x00, // "B"
    0x00, 0x00, 0x3E, 0x41, 0x41, 0x22, 0x00, 0x00, // "C"
    0x00, 0x00, 0x7F, 0x41, 0x41, 0x3E, 0x00, 0x00, // "D"
    0x00, 0x00, 0x7F, 0x49, 0x49, 0x41, 0x00, 0x00, // "E"
    0x00, 0x00, 0x7F, 0x48, 0x48, 0x40, 0x00, 0x00, // "F"
    0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, // ""
};

};
```

Use 2 nested for functions to make the LED dot matrix display a smiley face and loop it 500 times.

```
for(int j=0; j<500; j++){ //Repeat enough times to display the smiling face a period of time
    int x = 0x80;
    for(int i=0; i<8; i++){
        ledMatrix.shiftOut(HC595.Order.MSBFIRST, pic[i] & 0xff);
        ledMatrix.shiftOut(HC595.Order.MSBFIRST, ~x);
        ledMatrix.updateLatch();
        x >>= 1; //display the next column
        Thread.sleep(1);
    }
}
```

Display the array from character 0 and loop 10 times to ensure that it is visible to human eyes then move the array elements one by one to make the characters scroll.

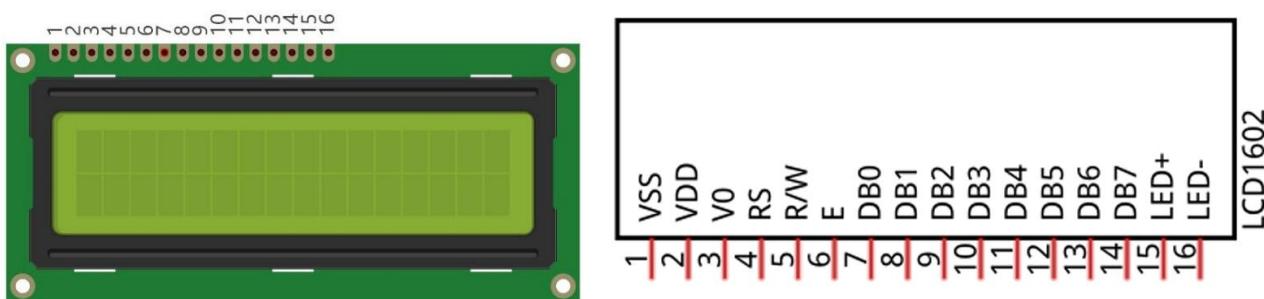
```
for(int k=0; k<data.length-8; k++){ //sizeof(data) total number of "0-F" columns
    for(int j=0; j<10; j++) {
        int x=0x80;
        for(int i=k; i<8+k; i++) {
            ledMatrix.shiftOut(HC595.Order.MSBFIRST, data[i] & 0xff);
            ledMatrix.shiftOut(HC595.Order.MSBFIRST, ~x);
            ledMatrix.updateLatch();
            x >>= 1;
            Thread.sleep(1);
        }
    }
}
```

# Chapter 18 LCD1602

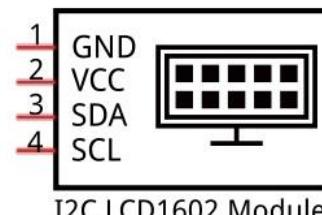
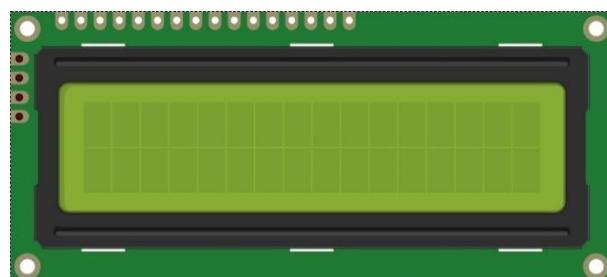
In this chapter, we will learn about the LCD1602 Display Screen,

## Project 18.1 I2C LCD1602

There are LCD1602 display screen and the I2C LCD. We will introduce both of them in this chapter. But what we use in this project is an I2C LCD1602 display screen. The LCD1602 Display Screen can display 2 lines of characters in 16 columns. It is capable of displaying numbers, letters, symbols, ASCII code and so on. As shown below is a monochrome LCD1602 Display Screen along with its circuit pin diagram



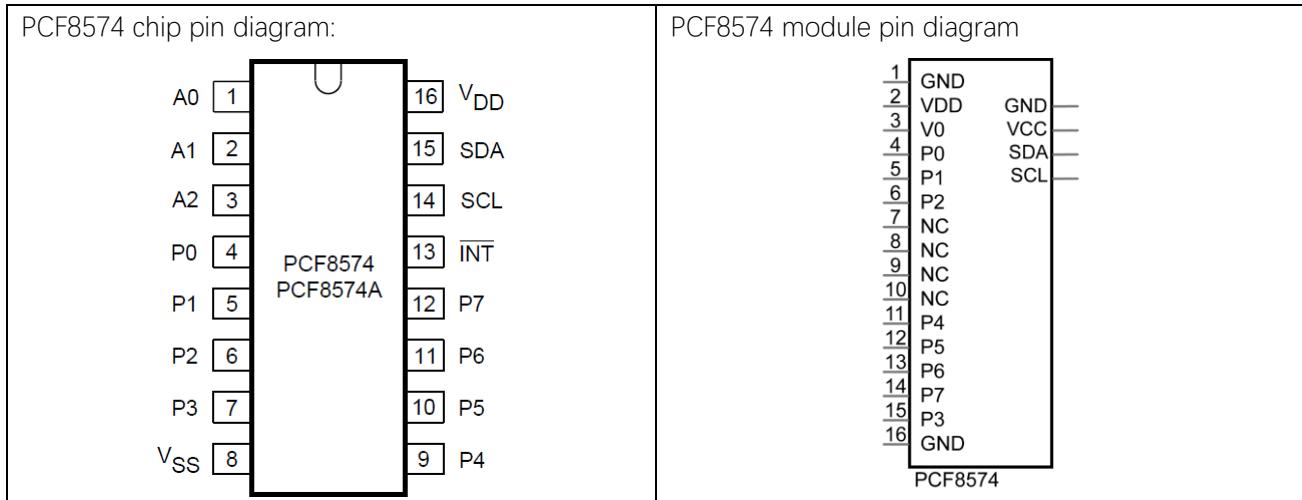
I2C LCD1602 Display Screen integrates a I2C interface, which connects the serial-input & parallel-output module to the LCD1602 Display Screen. This allows us to only use 4 lines to operate the LCD1602.



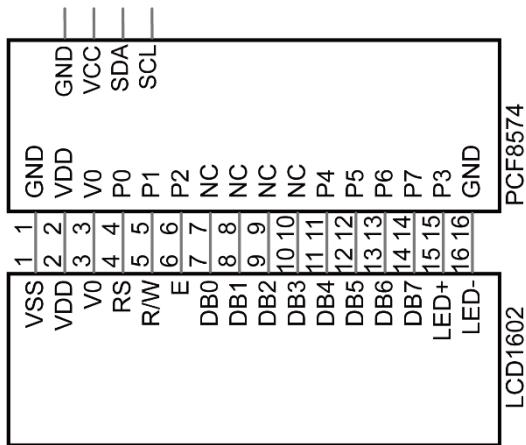
The serial-to-parallel IC chip used in this module is PCF8574T (PCF8574AT), and its default I2C address is 0x27(0x3F). You can also view the RPI bus on your I2C device address through command "i2cdetect -y 1" (refer to the "configuration I2C" section below).



Below is the PCF8574 chip pin diagram and its module pin diagram:



PCF8574 module pins and LCD1602 pins correspond to each other and are connected to each other:

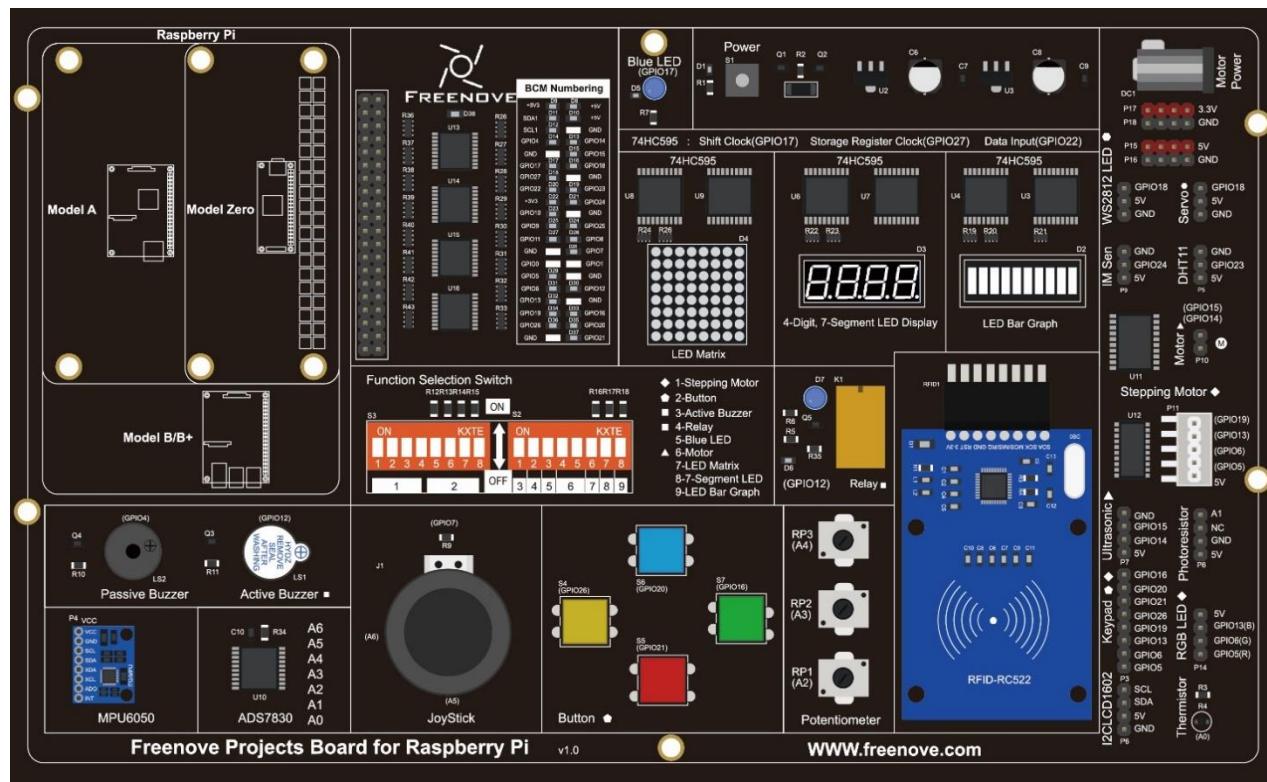


Because of this, as stated earlier, we only need 4 pins to control the 16 pins of the LCD1602 Display Screen through the I2C interface.

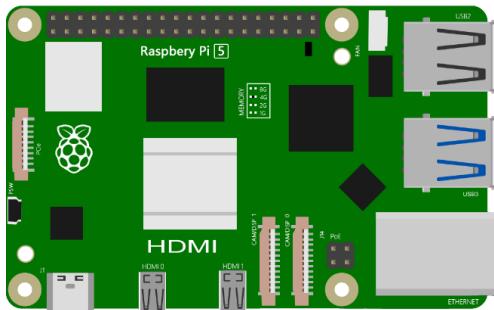
In this project, we will use the I2C LCD1602 to display some static characters and dynamic variables.

## Component List

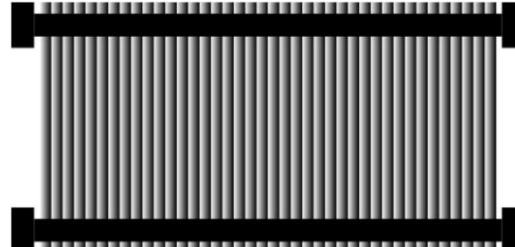
Freenove Projects Board for Raspberry Pi



Raspberry Pi



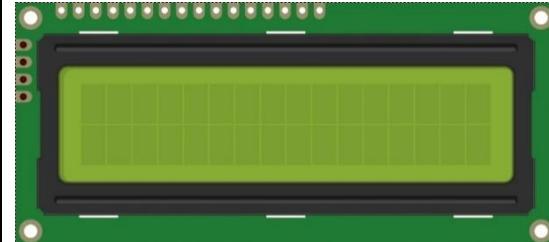
GPIO Ribbon Cable



Jumper Wire



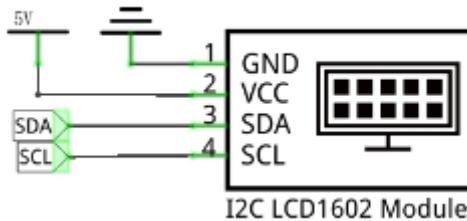
I2C LCD1602 Module



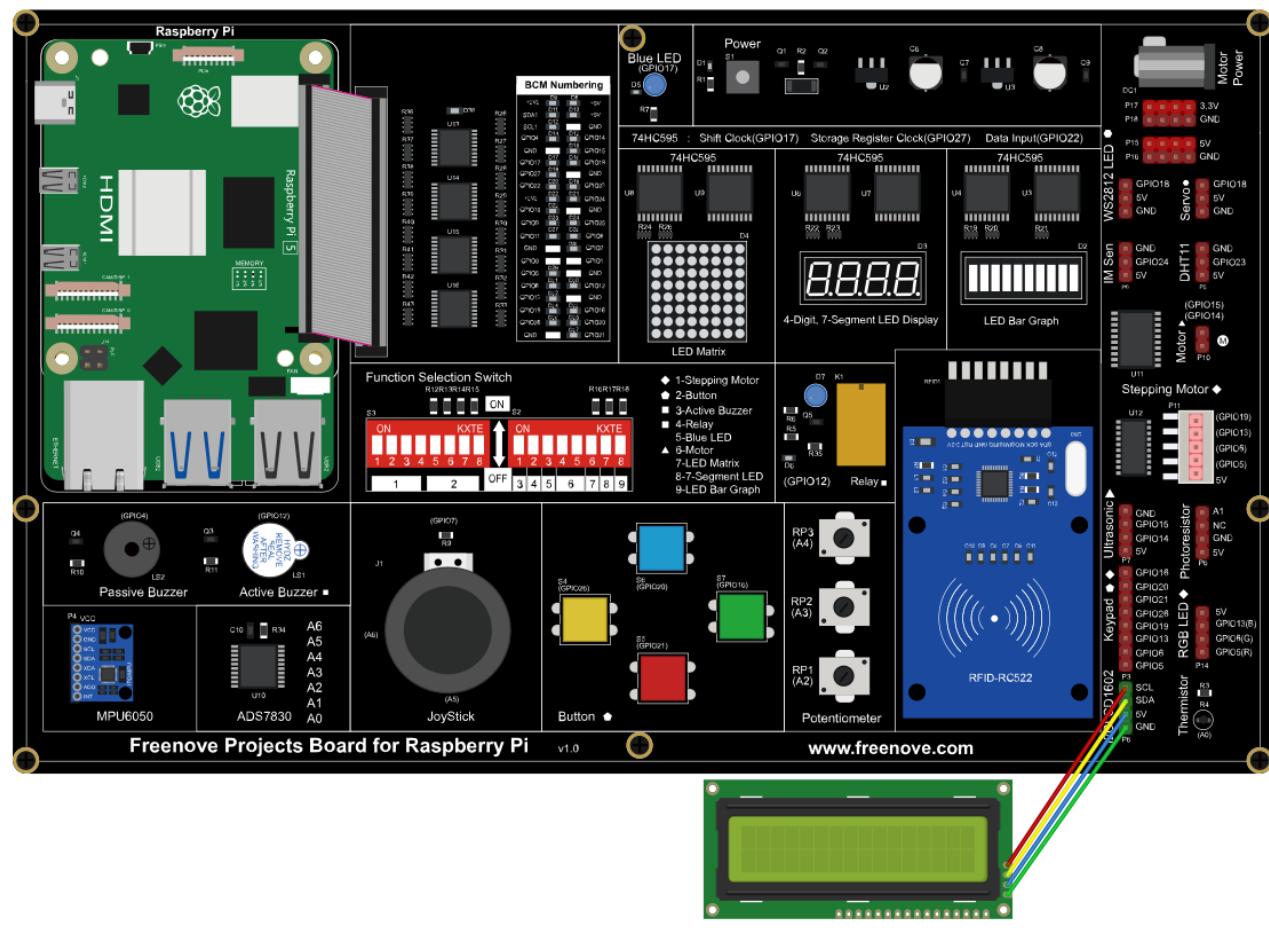
## Circuit

Note that the power supply for I2C LCD1602 in this circuit is 5V.

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this project, we will drive the LCD1602 display with I2C.

### Sketch\_18\_I2CLCD1602

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_18_I2CLCD1602
```

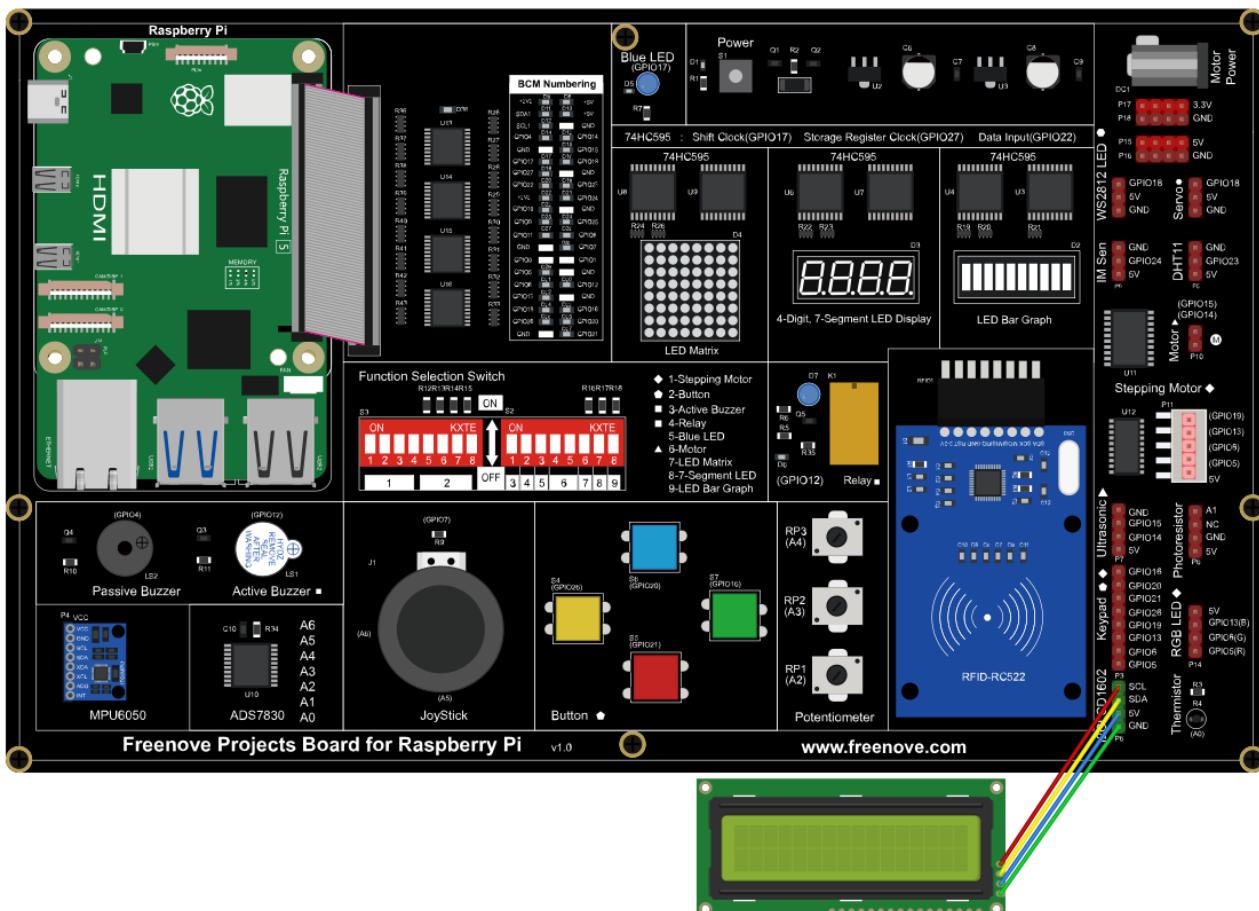
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_18_I2CLCD1602
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_18_I2CLCD1602 $
```

Enter the command to run the code.

```
jbang I2CLCD1602.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_18_I2CLCD1602
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_18_I2CLCD1602 $ jbang I2CLCD1602.java
```

When the code is running, you can see the first line of the display shows "Hello World", and the second line displays the running time in second.



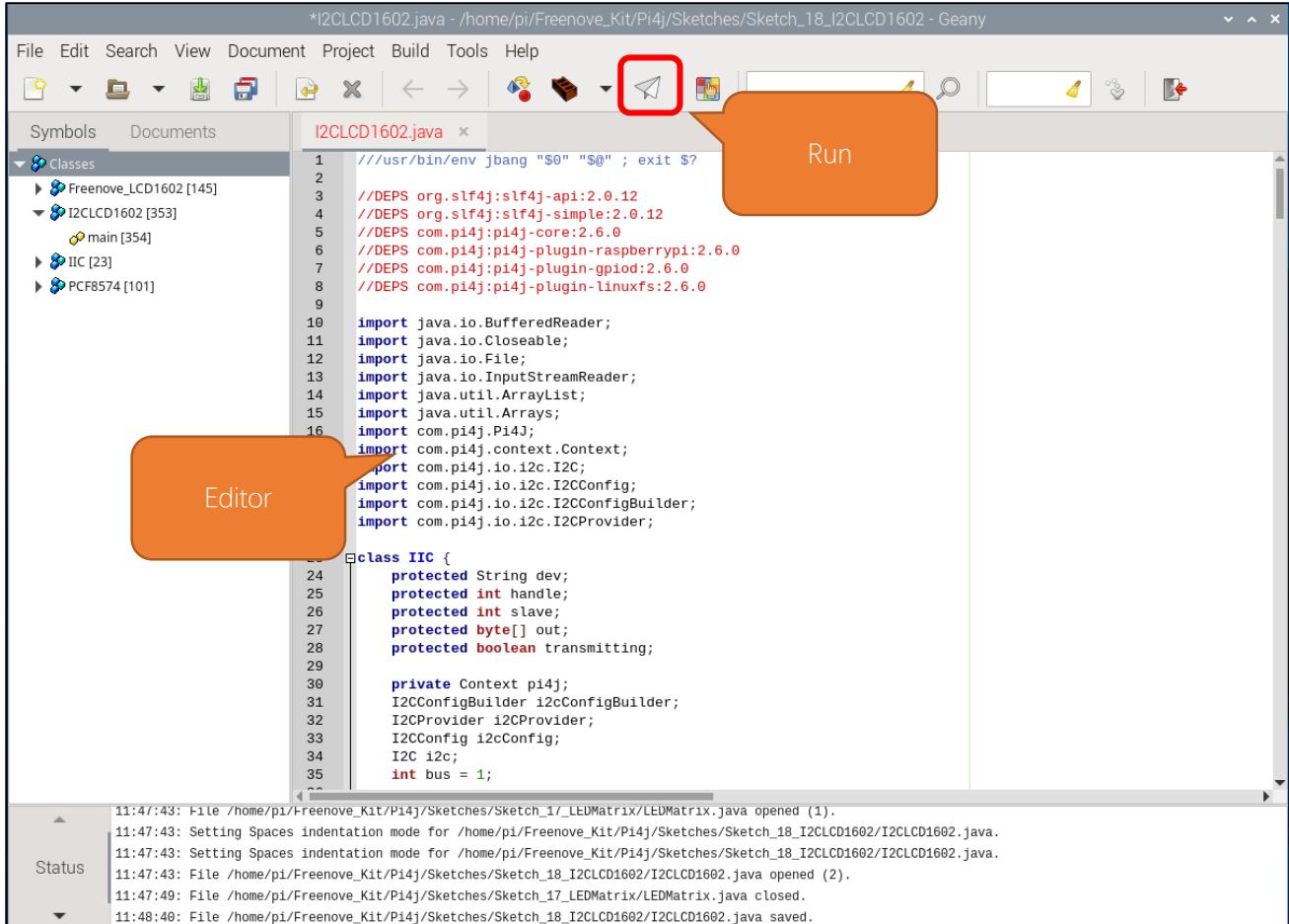
Press Ctrl+C to exit the program.

```
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown.
n. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_07_1_ADC $
```

You can run the following command to open the code with Geany to view and edit it.

### geany I2CLCD1602.java

Click the icon to run the code.



```
16 import java.util.ArrayList;
17 import java.util.Arrays;
18
19 import com.pi4j.Pi4J;
20 import com.pi4j.context.Context;
21 import com.pi4j.io.i2c.I2C;
22 import com.pi4j.io.i2c.I2CConfig;
23 import com.pi4j.io.i2c.I2CConfigBuilder;
24 import com.pi4j.io.i2c.I2CProvider;
25
26 class IIC {
27     protected String dev;
28     protected int handle;
29     protected int slave;
30     protected byte[] out;
31     protected boolean transmitting;
32     private Context pi4j;
33     I2CConfigBuilder i2cConfigBuilder;
34     I2CProvider i2CProvider;
35     I2CConfig i2cConfig;
36     I2C i2c;
37     int bus = 1;
38
39     public IIC(int bus) {
40         this.bus = bus;
41         constructor();
42     }
43     public IIC(String s) {
44         String b = s.split("i2c-")[1];
45         try {
46             this.bus = Integer.parseInt(b);
47         } catch (Exception e) {
48             this.bus = 1;
49         }
50         constructor();
51     }
52
53     private void constructor() {
54         pi4j = Pi4J.newAutoContext();
55         i2CProvider = pi4j.provider("linuxfs-i2c");
56         i2cConfigBuilder = I2C.newConfigBuilder(pi4j).bus(bus);
57     }
58     public void beginTransmission(int address) {
59         if (i2cConfig == null) {
```

```
60         i2cConfig = i2cConfigBuilder.device(address).build();
61     }
62     if (i2c == null) {
63         i2c = i2CProvider.create(i2cConfig);
64     }
65 }
66 public void write(int b) {
67     i2c.write(b);
68 }
69 public byte read() {
70     return i2c.readByte();
71 }
72 public byte[] read(int size) {
73     return i2c.readByteBuffer(size).array();
74 }
75 public void endTransmission() {
76     i2c.close();
77 }
78 public static String[] list() {
79     ArrayList<String> devs = new ArrayList<String>();
80     File dir = new File("/dev");
81     File[] files = dir.listFiles();
82     if (files != null) {
83         for (File file : files) {
84             if (file.getName().startsWith("i2c-")) {
85                 devs.add(file.getName());
86             }
87         }
88     }
89     String[] tmp = devs.toArray(new String[devs.size()]);
90     Arrays.sort(tmp);
91     return tmp;
92 }
93 }
94
95 class PCF8574 {
96     .....
97 }
98
99 class Freenove_LCD1602 {
100    .....
101 }
102
103 public class I2CLCD1602{
```

```

375 public static void main(String[] args) throws Exception {
376     PCF8574 pcf = new PCF8574(0x27);
377     Freenove_LCD1602 lcd;
378     lcd = new Freenove_LCD1602(pcf);
379     lcd.position(0, 0);           //show time on the lcd display
380     lcd.puts("Hello World.");
381     try{
382         int count = 0;
383         while(true){
384             String buf = "Count: " + count;
385             lcd.position(0, 1);    //show time on the lcd display
386             lcd.puts(buf);
387             Thread.sleep(1000);
388             count++;
389         }
390     }
391     catch (InterruptedException e) {
392         Thread.currentThread().interrupt();
393     }
394 }
395 }
```

Constructor, assigns the I2C bus to bus, and calls the constructor function to initialize the I2C bus.

```

public IIC(int bus) {
    this.bus = bus;
    constructor();
}

public IIC(String s) {
    String b = s.split("i2c-")[1];
    try {
        this.bus = Integer.parseInt(b);
    } catch (Exception e) {
        this.bus = 1;
    }
    constructor();
}
```

I2C constructor, initialize the I2C bus.

```

private void constructor() {
    pi4j = Pi4J.newAutoContext();
    i2CProvider = pi4j.provider("linuxfs-i2c");
    i2cConfigBuilder = I2C.newConfigBuilder(pi4j).bus(bus);
}
```

I2C bus acquisition function. Calling the list() function can obtain the names of all I2C buses currently existing on the Raspberry Pi.

```
public static String[] list() {
    ArrayList<String> devs = new ArrayList<String>();
    File dir = new File("/dev");
    File[] files = dir.listFiles();
    if (files != null) {
        for (File file : files) {
            if (file.getName().startsWith("i2c-")) {
                devs.add(file.getName());
            }
        }
    }
    String[] tmp = devs.toArray(new String[devs.size()]);
    Arrays.sort(tmp);
    return tmp;
}
```

Use the pi4j library to repackage the I2C functions. These functions refer to the classic usage of Arduino. This is to be compatible with the subsequent PCF8574 class and Freenove\_LCD1602 class, making it easier to drive LCD1602.

```
public void beginTransmission(int address) {
    if (i2cConfig == null) {
        i2cConfig = i2cConfigBuilder.device(address).build();
    }
    if (i2c == null) {
        i2c = i2CProvider.create(i2cConfig);
    }
}
public void write(int b) {
    i2c.write(b);
}
public byte read() {
    return i2c.readByte();
}
public byte[] read(int size) {
    return i2c.readByteBuffer(size).array();
}
public void endTransmission() {
    i2c.close();
}
```

The following are the two classes we wrote for LCD1602 in reference to Arduino. Here, we do not go into too much detail here. If you are interested in this code, you can use Geany to view the code.

```
class PCF8574 {
    .....
}

class Freenove_LCD1602 {
    .....
}
```

Initialize PCF8574 and Freenove\_LCD1602 classes, and assign the value to LCD.

```
PCF8574 pcf = new PCF8574(0x27);
Freenove_LCD1602 lcd;
lcd = new Freenove_LCD1602(pcf);
```

At the first lin of LCD1602, print the character "Hello World".

```
lcd.position(0, 0);           //show time on the lcd display
lcd.puts("Hello World.");
```

Print the character "Count" and the counts number at the second line every one second.

```
int count = 0;
while(true) {
    String buf = "Count: " + count;
    lcd.position(0, 1);   //show time on the lcd display
    lcd.puts(buf);
    Thread.sleep(1000);
    count++;
}
```

In Java, an `InterruptedException` is thrown when a thread's waiting, sleeping (e.g., using 'Thread.sleep()'), or other blocking operations are interrupted. When a thread is interrupted, its interrupted status is set to true, and any of these blocking operations will result in an 'InterruptedException' being thrown.

When 'InterruptedException' is capured, 'Thread.currentThread().interrupt()' is called keep the interrupt status, so that the thread can respond to the interruption request appropriately.

```
catch (InterruptedException e) {
    Thread.currentThread().interrupt();
}
```

# Chapter 19 Hygrothermograph DHT11

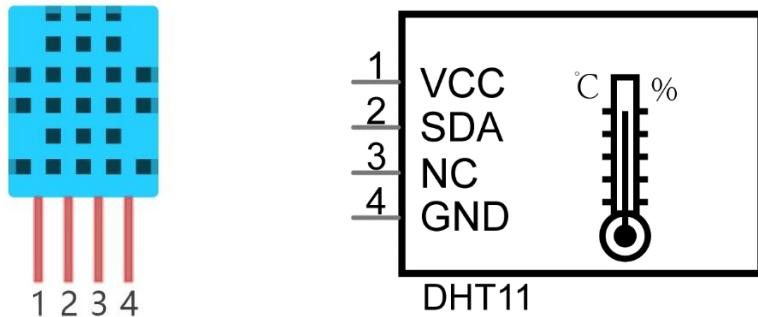
In this chapter, we will learn about a commonly used sensor called a Hygrothermograph DHT11.

## Project 19.1 Hygrothermograph

Hygrothermograph is an important tool in our lives to give us data on the temperature and humidity in our environment. In this project, we will use the RPi to read Temperature and Humidity data of the DHT11 Module.

### Component knowledge

The Temperature & Humidity Sensor DHT11 is a compound temperature & humidity sensor, and the output digital signal has been calibrated by its manufacturer.



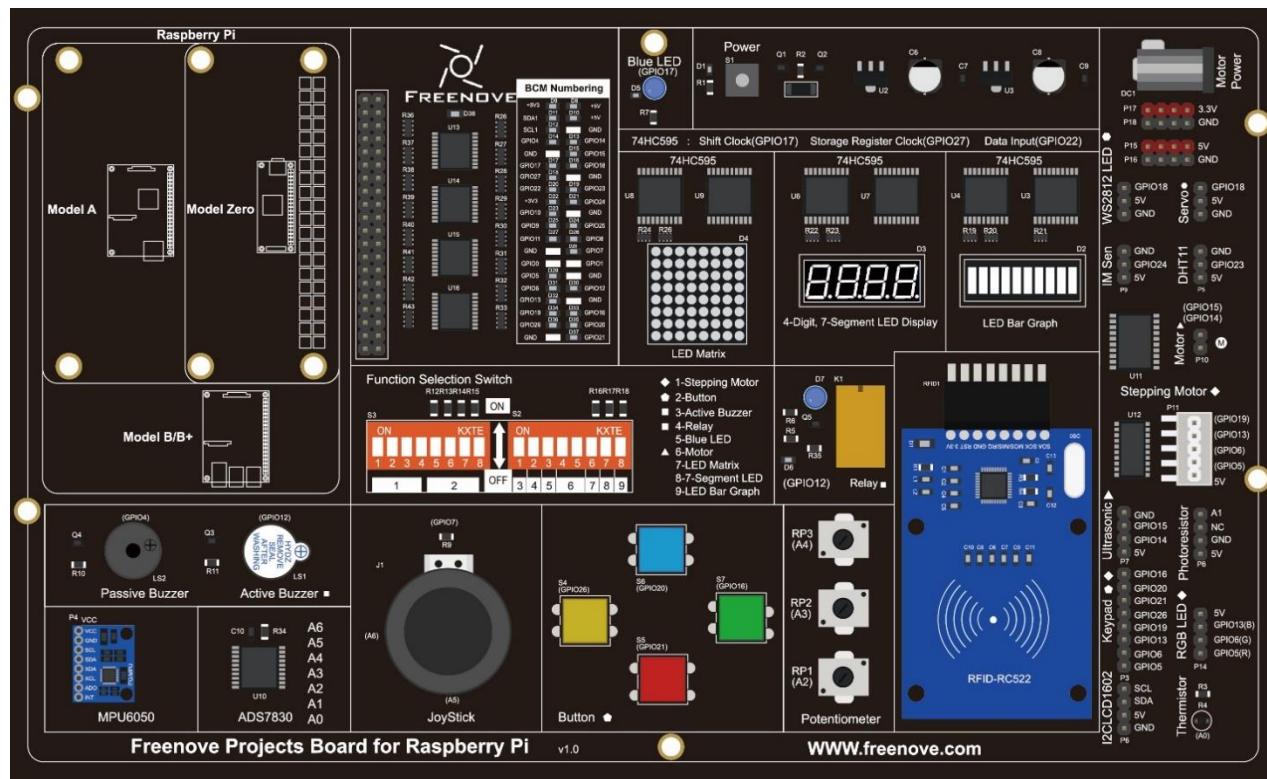
After being powered up, it will initialize in 1 second. Its operating voltage is within the range of 3.3V-5.5V.

The SDA pin is a data pin, which is used to communicate with other devices.

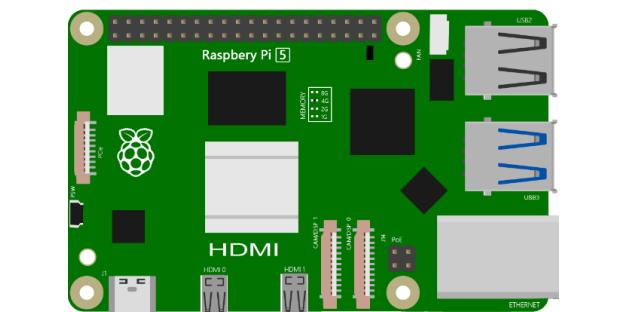
The NC pin (Not Connected Pin) is a type of pin found on various integrated circuit packages. Such pin has no functional purpose to the outside circuit (but may have an unknown functionality during manufacture and test). It should not be connected to any of the circuit connections.

## Component List

Freenove Projects Board for Raspberry Pi



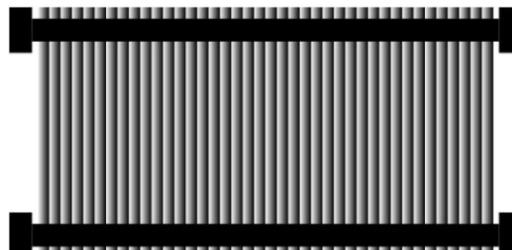
Raspberry Pi



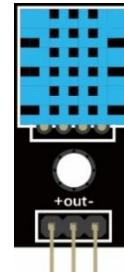
Jumper Wire



GPIO Ribbon Cable



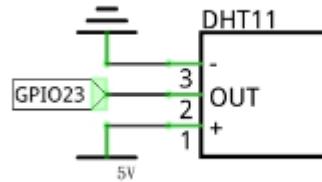
DHT11 Module



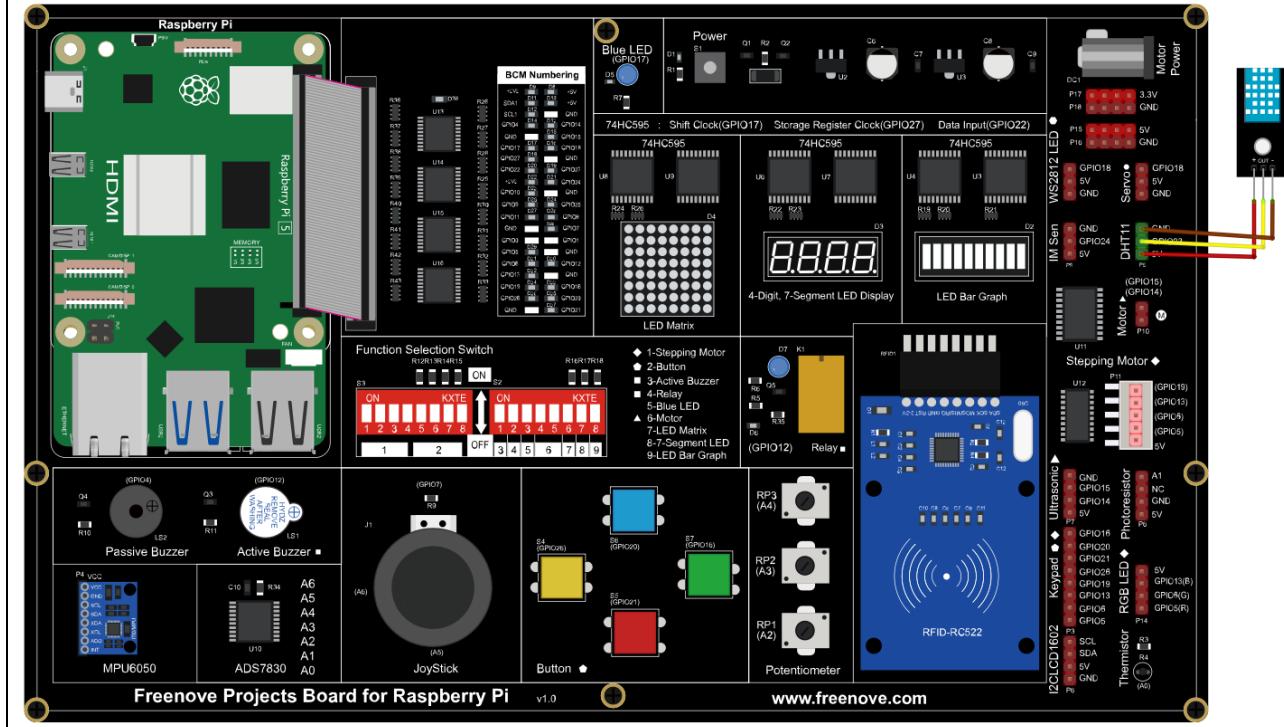


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

The Raspberry Pi can directly obtain data from the DHT11 sensor through system configuration. Before running the code, it is necessary to configure the Raspberry Pi first.

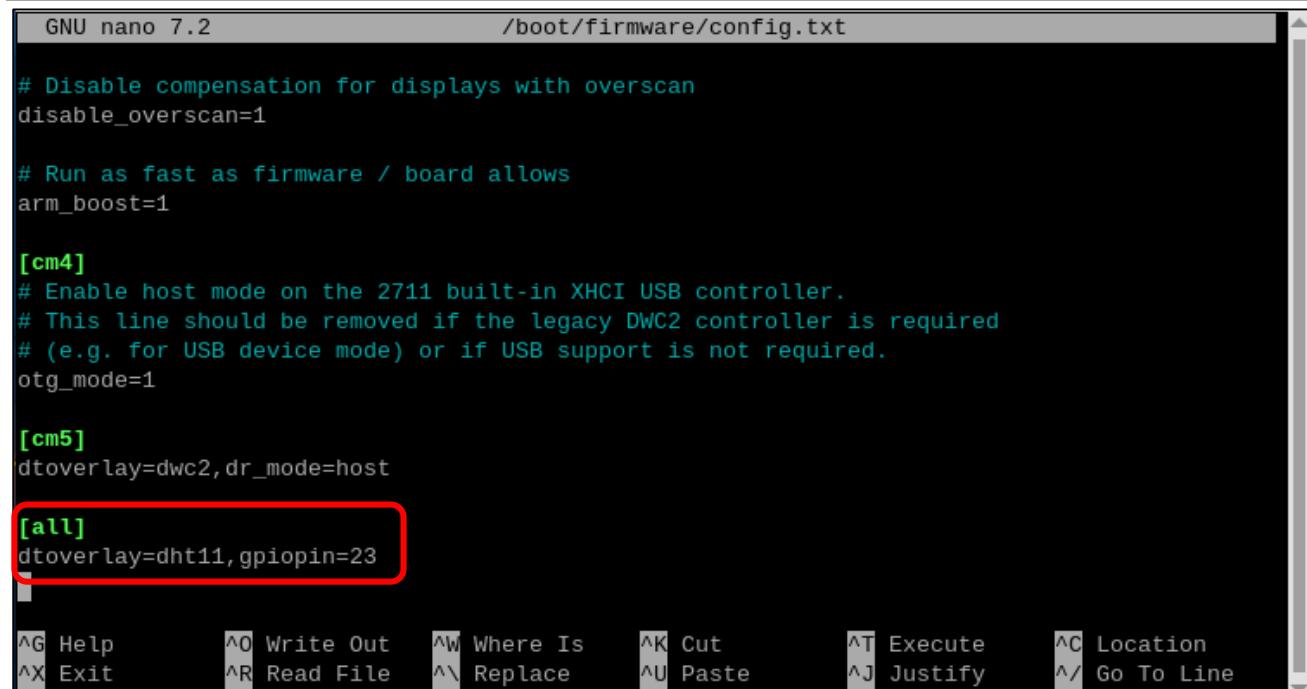
### Configure the config.txt file

Run the command to open the config.txt file.

```
sudo nano /boot/firmware/config.txt
```

Add the following line to the end of the file.

```
dtoverlay=dht11,gpiopin=23
```



```
GNU nano 7.2                               /boot/firmware/config.txt

# Disable compensation for displays with overscan
disable_overscan=1

# Run as fast as firmware / board allows
arm_boost=1

[cm4]
# Enable host mode on the 2711 built-in XHCI USB controller.
# This line should be removed if the legacy DWC2 controller is required
# (e.g. for USB device mode) or if USB support is not required.
otg_mode=1

[cm5]
dtoverlay=dwc2,dr_mode=host

[all]
dtoverlay=dht11,gpiopin=23
```

The screenshot shows the terminal window with the nano editor open to the config.txt file. The file contains several configuration options for the Raspberry Pi's hardware. A specific line, 'dtoverlay=dht11,gpiopin=23', is highlighted with a red rectangle, indicating it was manually added to the file. The terminal also shows standard nano editor key bindings at the bottom.

Press Ctrl+x, y, enter to save and exit the file. And then reboot your Raspberry Pi.

### Sketch\_19\_DHT11

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_19_DHT11
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_19_DHT11
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_19_DHT11 $
```

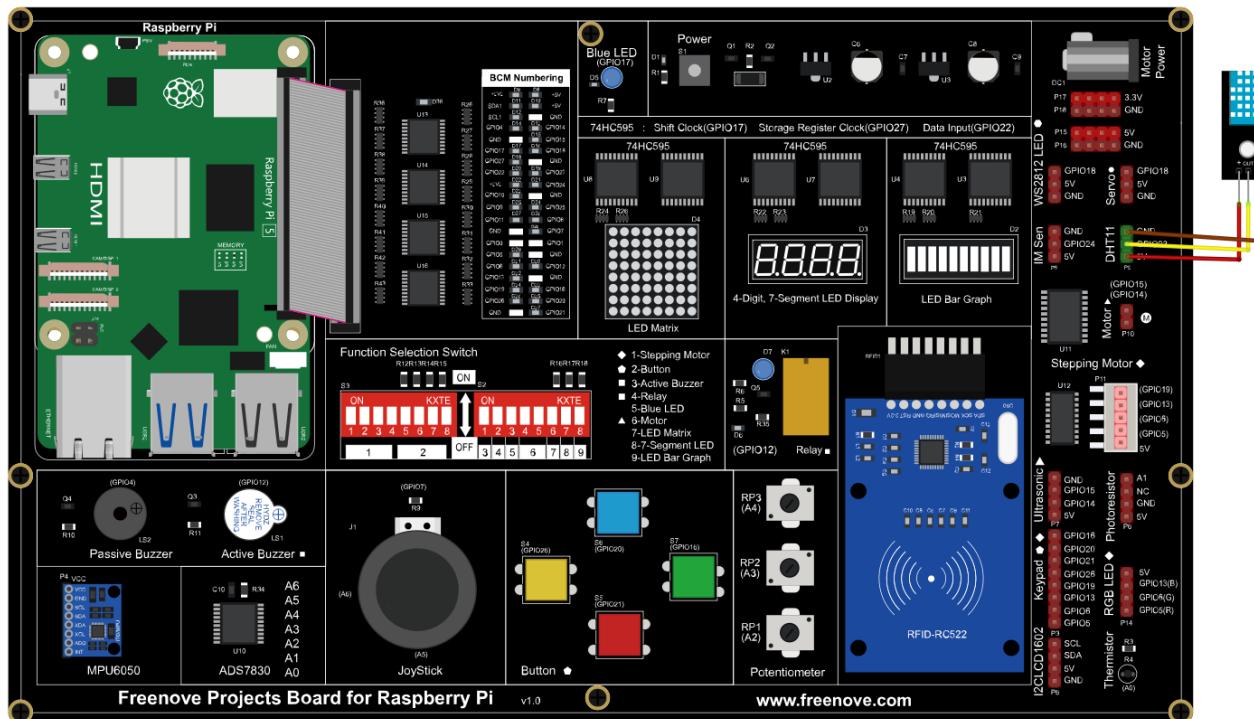
Enter the command to run the code.

```
jbang DHT11.java
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_19_DHT11
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_19_DHT11 $ jbang DHT11.java
```

When the code is running, the Raspberry Pi will continuously obtain the temperature and humidity data of DHT11 through GPIO23 and print it out.

Please note that DHT11 is a less sensitive sensor, and sometimes it takes a long time to obtain data, so please be patient.

```
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_19_DHT11 $ jbang DHT11.java
[jbang] Building jar for DHT11.java...
Temperature: 31.0°C
Humidity: 50.0%
Temperature: 28.0°C
Humidity: 56.0%
Temperature: 28.0°C
Humidity: 57.0%
```



Press Ctrl+C to exit the program.

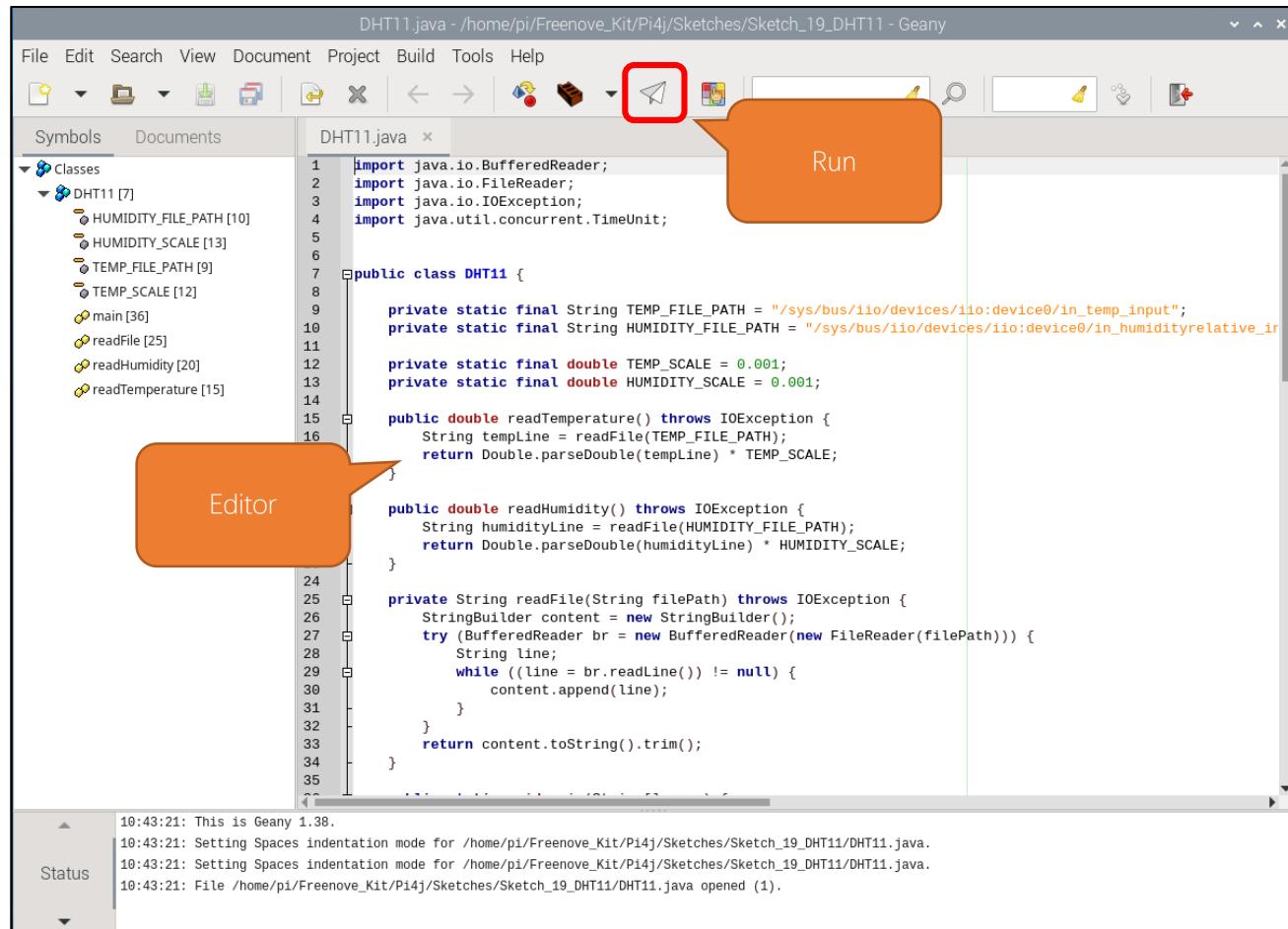
```
Temperature: 31.0°C
Humidity: 50.0%
Temperature: 28.0°C
Humidity: 56.0%
Temperature: 28.0°C
Humidity: 57.0%
Temperature: 28.0°C
Humidity: 57.0%
Temperature: 28.0°C
Humidity: 56.0%
Temperature: 28.0°C
Humidity: 54.0%
Temperature: 28.0°C
Humidity: 54.0%
Temperature: 28.0°C
Humidity: 54.0%
```

```
^Cpi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_19_DHT11 $
```

You can run the following command to open the code with Geany to view and edit it.

geany DHT11.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 import java.io.BufferedReader;
2 import java.io.FileReader;
3 import java.io.IOException;
4
5 public class DHT11 {
6     private static final String TEMP_FILE_PATH =
7         "/sys/bus/iio/devices/iio:device0/in_temp_input";
8     private static final String HUMIDITY_FILE_PATH =
9         "/sys/bus/iio/devices/iio:device0/in_humidityrelative_input";
10    private static final double TEMP_SCALE = 0.001;
11    private static final double HUMIDITY_SCALE = 0.001;
12
13    public double readTemperature() throws IOException {
14        String tempLine = readFile(TEMP_FILE_PATH);
```

```
13     return Double.parseDouble(tempLine) * TEMP_SCALE;
14 }
15
16 public double readHumidity() throws IOException {
17     String humidityLine = readFile(HUMIDITY_FILE_PATH);
18     return Double.parseDouble(humidityLine) * HUMIDITY_SCALE;
19 }
20
21 private String readfile(String filePath) throws IOException {
22     StringBuilder content = new StringBuilder();
23     try (BufferedReader br = new BufferedReader(new FileReader(filePath))) {
24         String line;
25         while ((line = br.readLine()) != null) {
26             content.append(line);
27         }
28     }
29     return content.toString().trim();
30 }
31
32 public static void main(String[] args) {
33     DHT11 dht11 = new DHT11();
34     while (true) {
35         try {
36             double temperature = dht11.readTemperature();
37             double humidity = dht11.readHumidity();
38             if (humidity >= 0 && humidity <= 100) {
39                 System.out.println("Temperature: " + temperature + "° C");
40                 System.out.println("Humidity: " + humidity + "%");
41             }
42             Thread.sleep(2000);
43         } catch (IOException e) {
44             if (!"Input/output error".equals(e.getMessage())) {
45                 e.printStackTrace();
46             }
47         } catch (InterruptedException e) {
48             Thread.currentThread().interrupt();
49             break;
50         }
51     }
52 }
53 }
```

Defines the file storage path for temperature and humidity data.

```
private static final String TEMP_FILE_PATH =
    "/sys/bus/iio/devices/iio:device0/in_temp_input";
private static final String HUMIDITY_FILE_PATH =
    "/sys/bus/iio/devices/iio:device0/in_humidityrelative_input";
```

Below are the functions for getting temperature and humidity. The raw data read by the Raspberry Pi from the file needs to be converted to 0.001 times the original value.

```
private static final double TEMP_SCALE = 0.001;
private static final double HUMIDITY_SCALE = 0.001;

public double readTemperature() throws IOException {
    String tempLine = readFile(TEMP_FILE_PATH);
    return Double.parseDouble(tempLine) * TEMP_SCALE;
}

public double readHumidity() throws IOException {
    String humidityLine = readFile(HUMIDITY_FILE_PATH);
    return Double.parseDouble(humidityLine) * HUMIDITY_SCALE;
}
```

The method to read the contents of a file, loop through each line in the file, and append it to 'content'.

```
private String readFile(String filePath) throws IOException {
    StringBuilder content = new StringBuilder();
    try (BufferedReader br = new BufferedReader(new FileReader(filePath))) {
        String line;
        while ((line = br.readLine()) != null) {
            content.append(line);
        }
    }
    return content.toString().trim();
}
```

Create an instance of the DHT11 class, read the temperature and humidity data every 2 seconds, and print it out if the data is normal; if the data is not normal, do not print it. and retrieve the next temperature and humidity data instead.

```
DHT11 dht11 = new DHT11();
while (true) {
    try {
        double temperature = dht11.readTemperature();
        double humidity = dht11.readHumidity();
        if (humidity >= 0 && humidity <= 100) {
            System.out.println("Temperature: " + temperature + "° C");
            System.out.println("Humidity: " + humidity + "%");
        }
        Thread.sleep(2000);
    } catch (IOException e) {
        if (!"Input/output error".equals(e.getMessage())) {
            e.printStackTrace();
        }
    } catch (InterruptedException e) {
        Thread.currentThread().interrupt();
        break;
    }
}
```

Please note that after you finish studying this chapter, you should comment out the line related to DHT11 in the 'config.txt' file to avoid errors when Raspberry Pi uses GPIO23 in subsequent chapters.

Run the command to open the config.txt file.

```
sudo nano /boot/firmware/config.txt
```

Add the "#" in front of the line.

```
#dtoverlay=dht11,gpiopin=23
```

```
[cm4]
# Enable host mode on the 2711 built-in XHCI USB controller.
# This line should be removed if the legacy DWC2 controller is required
# (e.g. for USB device mode) or if USB support is not required.
otg_mode=1

[cm5]
dtoverlay=dwc2,dr_mode=host

[all]
#dtoverlay=dht11,gpiopin=23
```

<b>^G</b> Help	<b>^O</b> Write Out	<b>^W</b> Where Is	<b>^K</b> Cut	<b>^T</b> Execute	<b>^C</b> Location
<b>^X</b> Exit	<b>^R</b> Read File	<b>^V</b> Replace	<b>^U</b> Paste	<b>^J</b> Justify	<b>^/</b> Go To Line

Save the file and reboot your Raspberry Pi.

# Chapter 20 Matrix Keypad

Earlier we learned about a single Push Button Switch. In this chapter, we will learn about Matrix Keyboards, which integrates a number of Push Button Switches as Keys for the purposes of Input.

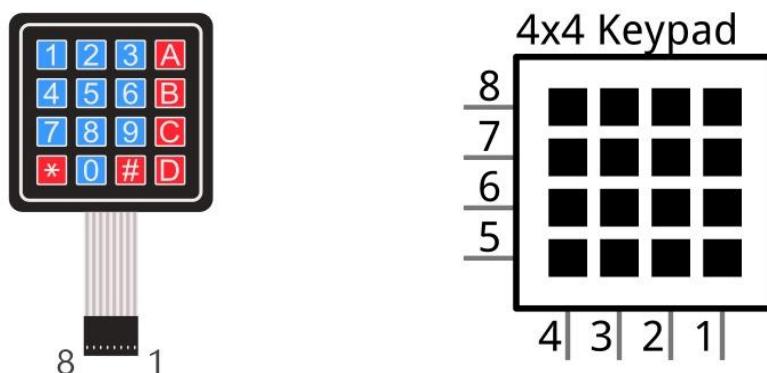
## Project 20.1 Matrix Keypad

In this project, we will attempt to get every key code on the Matrix Keypad to work.

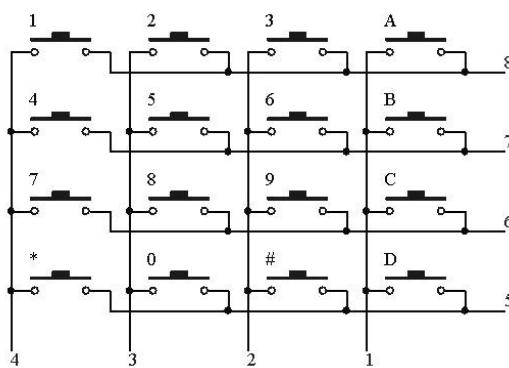
### Component knowledge

#### 4x4 Matrix Keypad

A Keypad Matrix is a device that integrates a number of keys in one package. As is shown below, a 4x4 Keypad Matrix integrates 16 keys (think of this as 16 Push Button Switches in one module):



Similar to the integration of an LED Matrix, the 4x4 Keypad Matrix has each row of keys connected with one pin and this is the same for the columns. Such efficient connections reduce the number of processor ports required. The internal circuit of the Keypad Matrix is shown below.

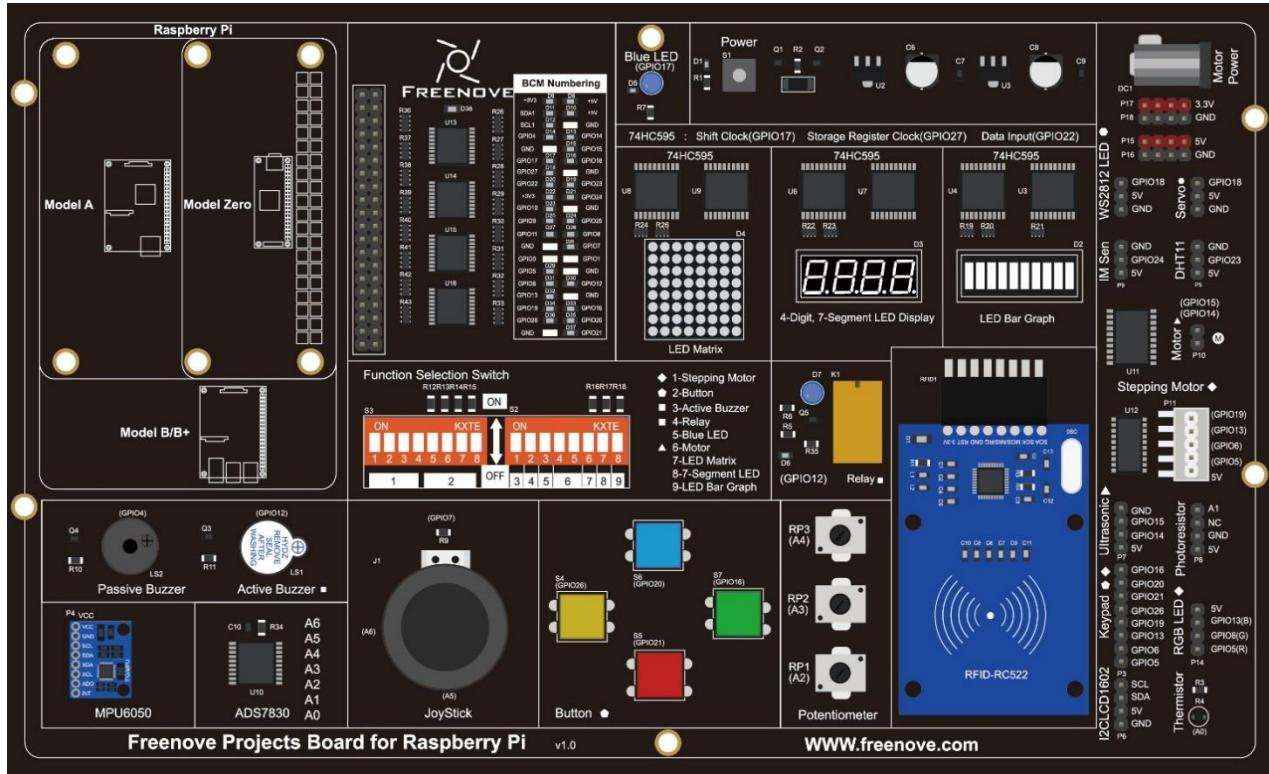


The method of usage is similar to the Matrix LED, by using a row or column scanning method to detect the state of each key's position by column and row. Take column scanning method as an example, send low level to the first 1 column (Pin1), detect level state of rows 5, 6, 7, 8 to judge whether the keys A, B, C, D are pressed. Then send low level to columns 2, 3, 4 in turn to detect whether other keys are pressed. Therefore, you can get the state of all of the keys.



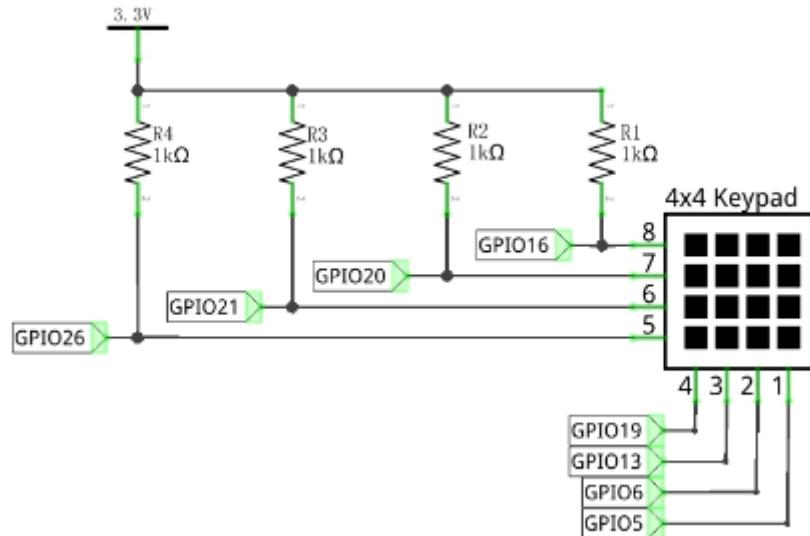
## Component List

Freenove Projects Board for Raspberry Pi

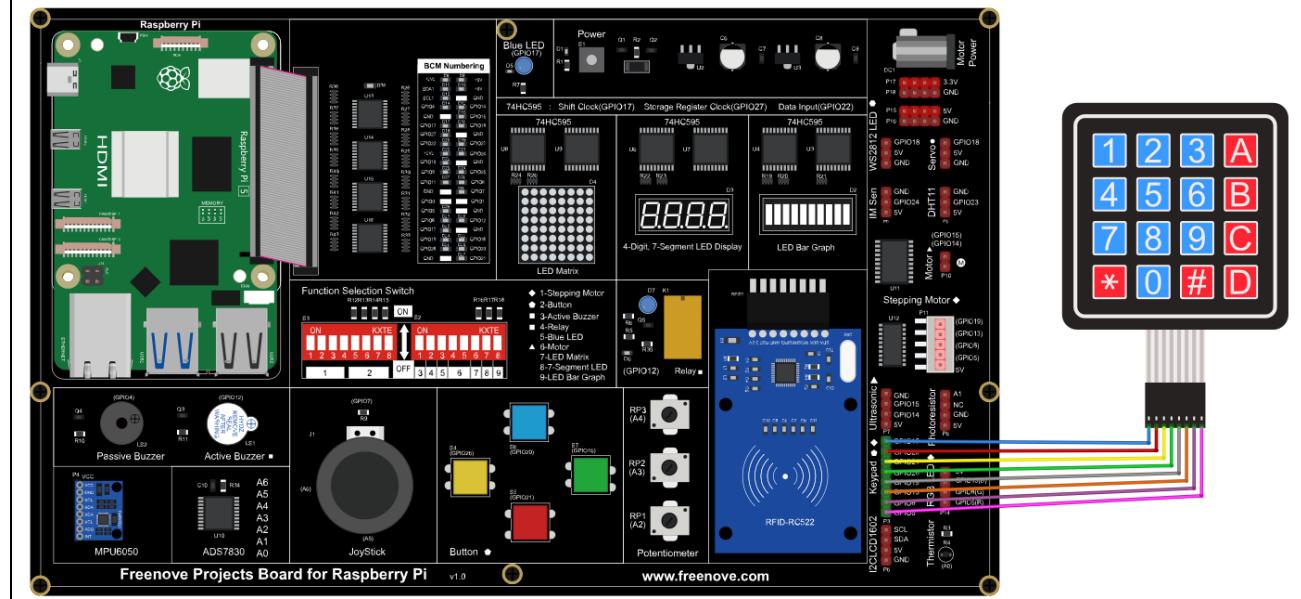


## Circuit

Schematic diagram



Hardware connection.



If you have any concerns, please send an email to: support@freenove.com

## Sketch

In this chapter, we will learn to use a martrix keypad.

### Sketch\_20\_MatrixKeypad

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_20_MatrixKeypad
```

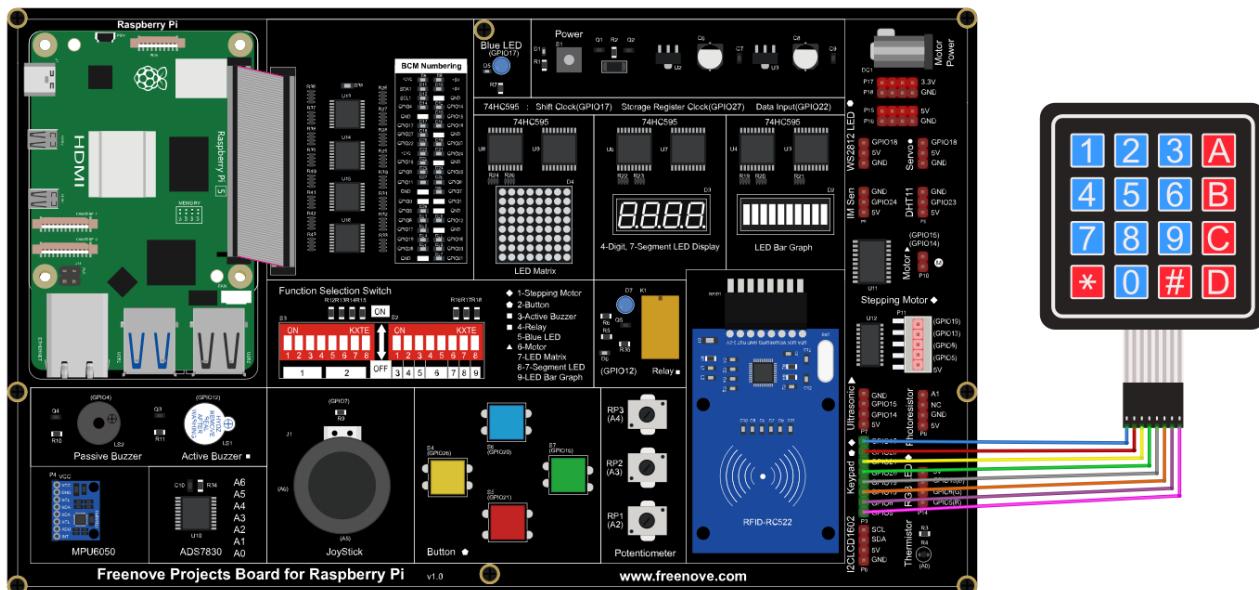
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_20_MatrixKeypad
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_20_MatrixKeypad $
```

Enter the command to run the code.

```
jbang MatrixKeypad.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_20_MatrixKeypad
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_20_MatrixKeypad $ jbang MatrixKeypad.java
```

When the code is running, press any key on the keypad and the correspnding value will be printed on the terminal.



```
[main] INFO com.pi4j.util.Console - key:1
[main] INFO com.pi4j.util.Console - key:2
[main] INFO com.pi4j.util.Console - key:3
[main] INFO com.pi4j.util.Console - key:A
[main] INFO com.pi4j.util.Console - key:4
[main] INFO com.pi4j.util.Console - key:5
[main] INFO com.pi4j.util.Console - key:6
[main] INFO com.pi4j.util.Console - key:B
[main] INFO com.pi4j.util.Console - key:7
[main] INFO com.pi4j.util.Console - key:8
[main] INFO com.pi4j.util.Console - key:9
[main] INFO com.pi4j.util.Console - key:C
[main] INFO com.pi4j.util.Console - key:*
[main] INFO com.pi4j.util.Console - key:0
[main] INFO com.pi4j.util.Console - key:#
```

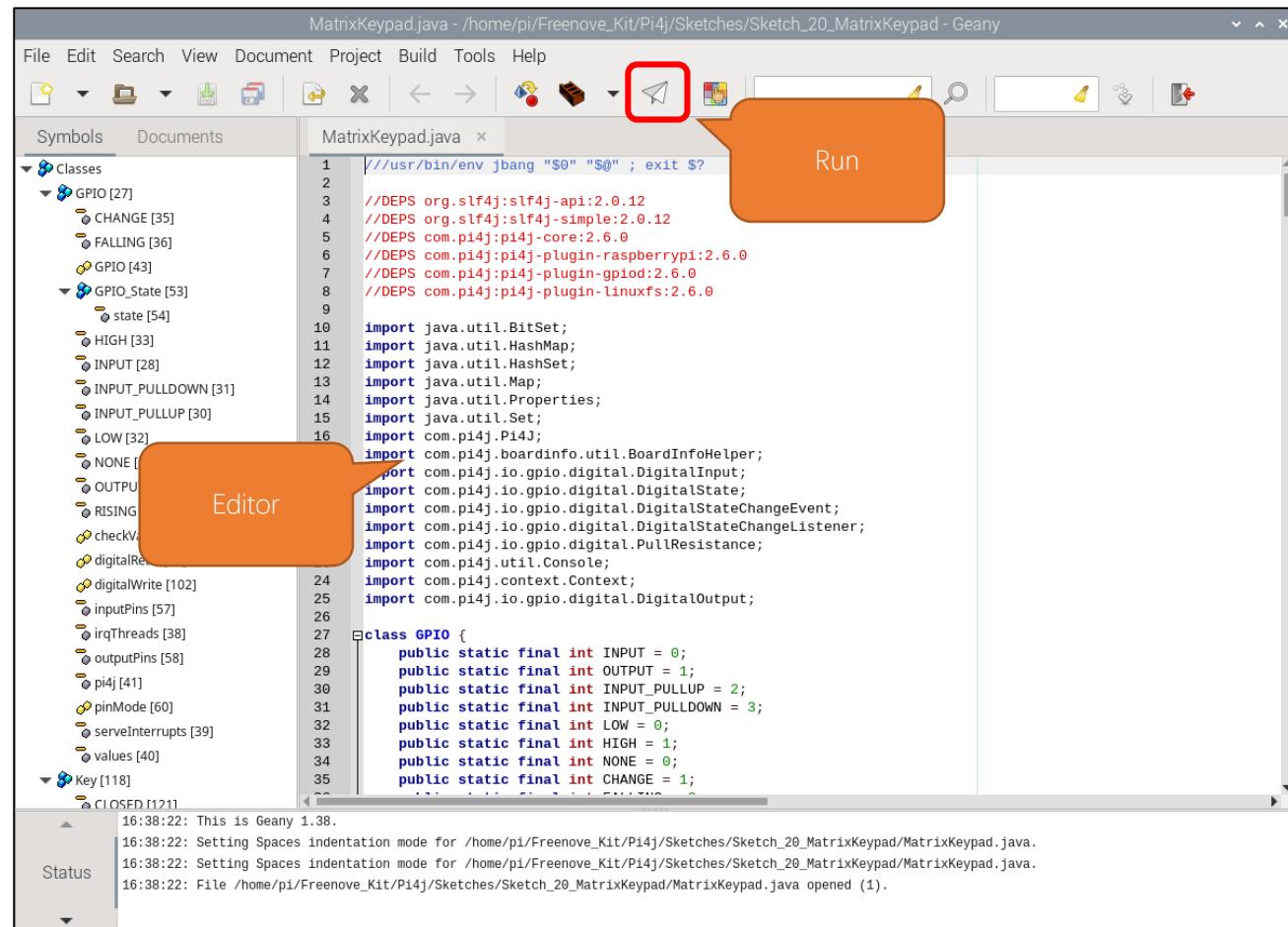
Press Ctrl+C to exit the program.

```
[pi4j-shutdown] INFO com.pi4j.plugin.gpiod.provider.gpio.digital.GpioDDigitalInput - Shutdown input listener for DIN-20
[pi4j-shutdown] INFO com.pi4j.plugin.gpiod.provider.gpio.digital.GpioDDigitalInput - Shutdown input listener for DIN-21
[pi4j-shutdown] INFO com.pi4j.plugin.gpiod.provider.gpio.digital.GpioDDigitalInput - Shutdown input listener for DIN-26
[pi4j-shutdown] INFO com.pi4j.plugin.gpiod.provider.gpio.digital.GpioDDigitalInput - Shutdown input listener for DIN-16
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
```

You can run the following command to open the code with Geany to view and edit it.

### geany MatrixKeypad.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
//usr/bin/env jbang "$0" "$@" ; exit $?

//DEPS org.slf4j:slf4j-api:2.0.12
//DEPS org.slf4j:slf4j-simple:2.0.12
//DEPS com.pi4j:pi4j-core:2.6.0
//DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
//DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
//DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0

import java.util.BitSet;
import java.util.HashMap;
import java.util.HashSet;
import java.util.Map;
import java.util.Properties;
import java.util.Set;
```



```
16 import com.pi4j.Pi4J;
17 import com.pi4j.boardinfo.util.BoardInfoHelper;
18 import com.pi4j.io.gpio.digital.DigitalInput;
19 import com.pi4j.io.gpio.digital.DigitalState;
20 import com.pi4j.io.gpio.digital.DigitalChangeEvent;
21 import com.pi4j.io.gpio.digital.DigitalStateChangeListener;
22 import com.pi4j.io.gpio.digital.PullResistance;
23 import com.pi4j.util.Console;
24 import com.pi4j.context.Context;
25 import com.pi4j.io.gpio.digital.DigitalOutput;
26
27 class GPIO {
...
    ....
}
111 }
112
113 //class Key:Define some of the properties of Key
114 class Key {
...
    ....
}
127 }
128
129 class Keypad {
...
    ....
}
309 }
310
311 public class MatrixKeypad{
312     final static char[] keys = { //key code
313         '1', '2', '3', 'A',
314         '4', '5', '6', 'B',
315         '7', '8', '9', 'C',
316         '*', '0', '#', 'D'
317     };
318
319     final static int[] rowsPins = {16, 20, 21, 26}; //Connect to the row pinouts of the keypad
320     final static int[] colsPins = {19, 13, 6, 5}; //Connect to the column pinouts of the keypad
321     private static final Context pi4j = Pi4J.newAutoContext();
322     static Keypad kp = new Keypad(pi4j, keys, rowsPins, colsPins);
323
324     public static void myPrintln(String format, Object... args) {
325         Console console = new Console();
326         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
327     }
328
329     public static void main(String[] args) throws Exception {
330         Runtime.getRuntime().addShutdownHook(new Thread(() -> {
```

```

331     System.out.println("Shutting down Pi4J context... ");
332     if (pi4j!= null) {
333         pi4j.shutdown();
334     }
335 });
336
337     try {
338         while(true) {
339             char kkey = kp.getKey();
340             if (kkey != '\0') {
341                 myPrintln("key:%c", kkey);
342             }
343             Thread.sleep(10);
344         }
345     }catch (InterruptedException e) {
346         myPrintln("Interrupted. Exiting... ");
347     }
348     finally {
349         ;
350     }
351 }
352 }
```

Re-encapsulate the GPIO functions using the Pi4J library, with these functions referring to the classic usage of Arduino. This is done to ensure compatibility with the later Key class and Keypad class, making matrix buttons easier to use. If you are interested in this code, please review it, as we will include detailed comments within the code.

```

class GPIO {
    .....
}

//class Key:Define some of the properties of Key
class Key {
    .....
}

class Keypad {
    .....
}
```

Define the key values corresponding to the matrix keyboard.

```
final static char[] keys = { //key code
    '1', '2', '3', 'A',
    '4', '5', '6', 'B',
    '7', '8', '9', 'C',
    '*', '0', '#', 'D'
};
```

Define pin numbers for the row and column the matrix keyboard.

```
final static int[] rowsPins = {16, 20, 21, 26};//Connect to the row pinouts of the keypad
final static int[] colsPins = {19, 13, 6, 5};//Connect to the column pinouts of the keypad
```

Add a shutdown hook to ensure the Pi4J context is closed properly.

```
Runtime.getRuntime().addShutdownHook(new Thread(() -> {
    System.out.println("Shutting down Pi4J context...");
    if (pi4j!= null) {
        pi4j.shutdown();
    }
}));
```

The key value is read from the matrix keyboard every 10 milliseconds. If the key value is not detected as empty, it is printed on the terminal interface.

```
while(true) {
    char kkey = kp.getKey();
    if (kkey != '\0') {
        myPrintln("key:%c", kkey);
    }
    Thread.sleep(10);
}
```

# Chapter 21 Infrared Motion Sensor

In this chapter, we will learn a widely used sensor, Infrared Motion Sensor.

## Project 21.1 PIR Infrared Motion Detector with LED Indicator

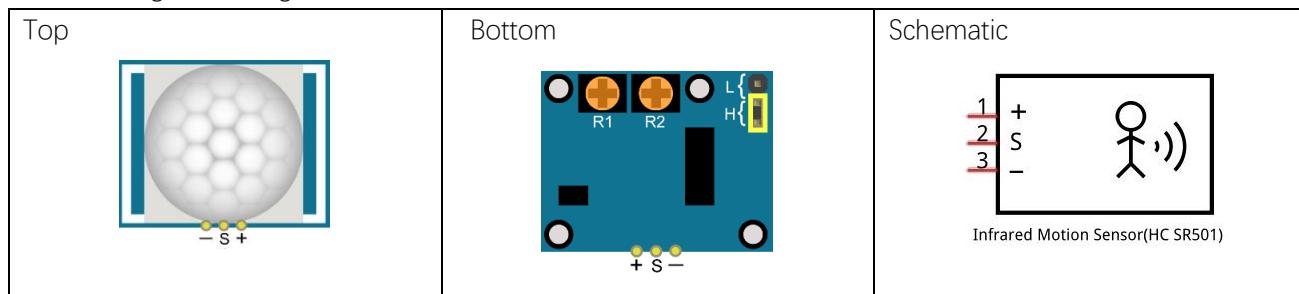
In this project, we will make a Motion Detector, with the human body infrared pyroelectric sensors.

When someone is in close proximity to the Motion Detector, it will automatically light up and when there is no one close by, it will be out.

This Infrared Motion Sensor can detect the infrared spectrum (heat signatures) emitted by living humans and animals.

### Component Knowledge

The following is the diagram of the Infrared Motion Sensor (HC SR-501) a PIR Sensor:



Description:

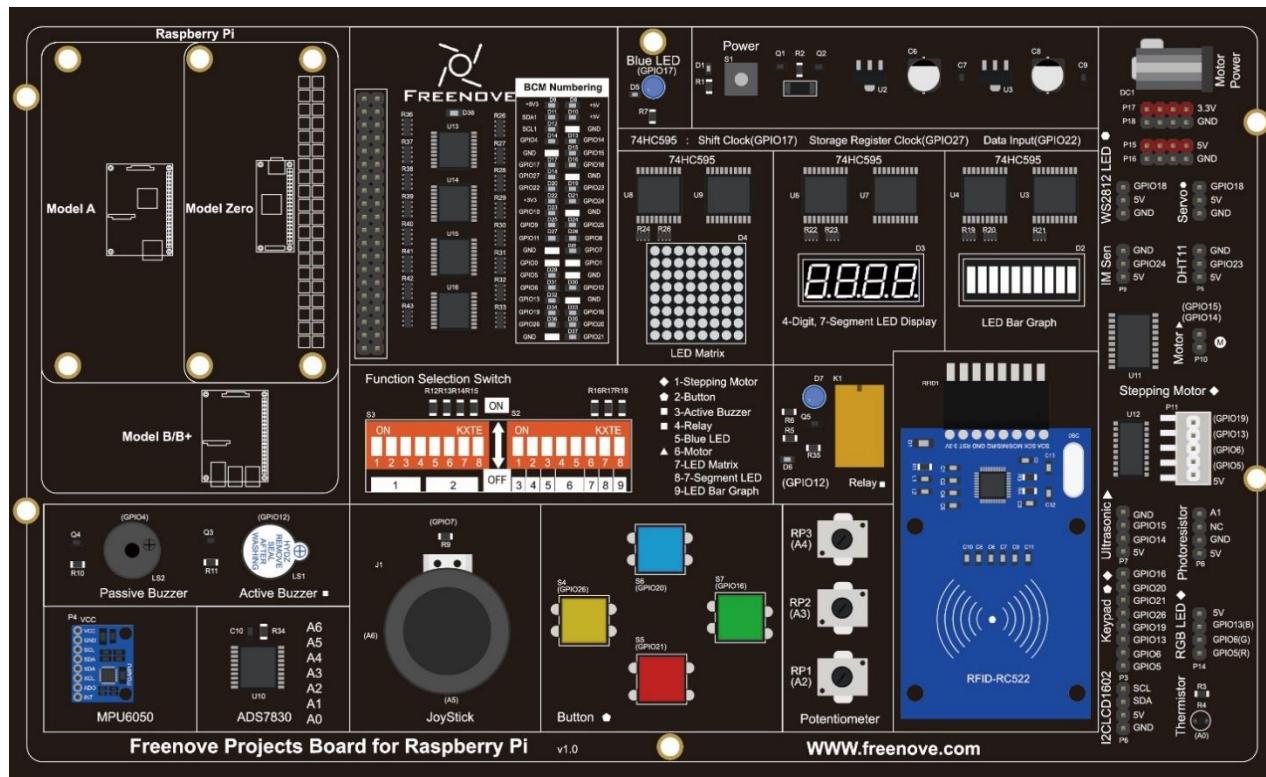
1. Working voltage: 5v-20v (DC) Static current: 65uA.
2. Automatic Trigger. When a living body enters into the active area of sensor, the module will output high level (3.3V). When the body leaves the sensor's active detection area, it will output high level lasting for time period T, then output low level (0V). Delay time T can be adjusted by the potentiometer R1.
3. According to the position of Fresnel lenses dome, you can choose non-repeatable trigger modes or repeatable modes.
  - L: non-repeatable trigger mode. The module outputs high level after sensing a body, then when the delay time is over, the module will output low level. During high-level time, the sensor no longer actively senses bodies.
  - H: repeatable trigger mode. The distinction from the L mode is that it can sense a body until that body leaves during the period of high-level output. After this, it starts to time and output low level after delaying T time.
4. Induction block time: the induction will stay in block condition and does not induce external signal at lesser time intervals (less than delay time) after outputting high level or low level
5. Initialization time: the module needs about 1 minute to initialize after being powered ON. During this period, it will alternately output high or low level.
6. One characteristic of this sensor is when a body moves close to or moves away from the sensor's dome edge, the sensor will work at high sensitively. When a body moves close to or moves away from the sensor'

s dome in a vertical direction (perpendicular to the dome), the sensor cannot detect well (please take note of this deficiency). Actually, this makes sense when you consider that this sensor is usually placed on a ceiling as part of a security product. Note: The Sensing Range (distance before a body is detected) is adjusted by the potentiometer.

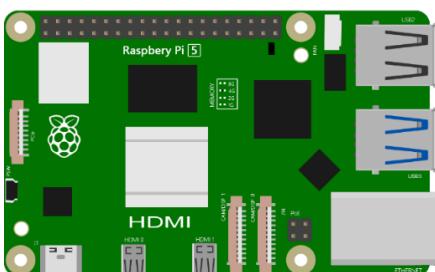
We can regard this sensor as a simple inductive switch when in use.

## Component List

Freenove Projects Board for Raspberry Pi



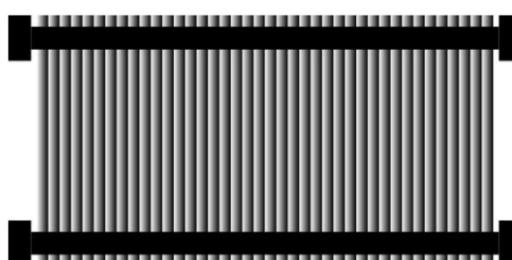
Raspberry Pi



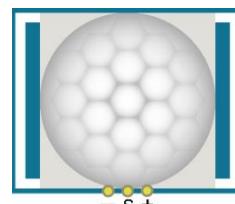
Jumper Wire



GPIO Ribbon Cable

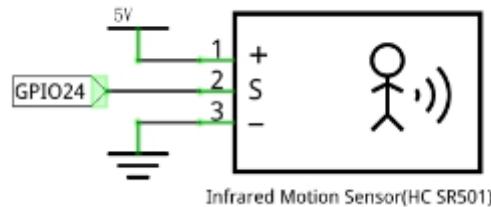


HC SR501

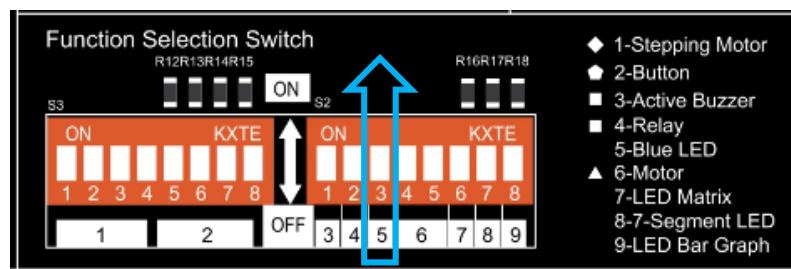
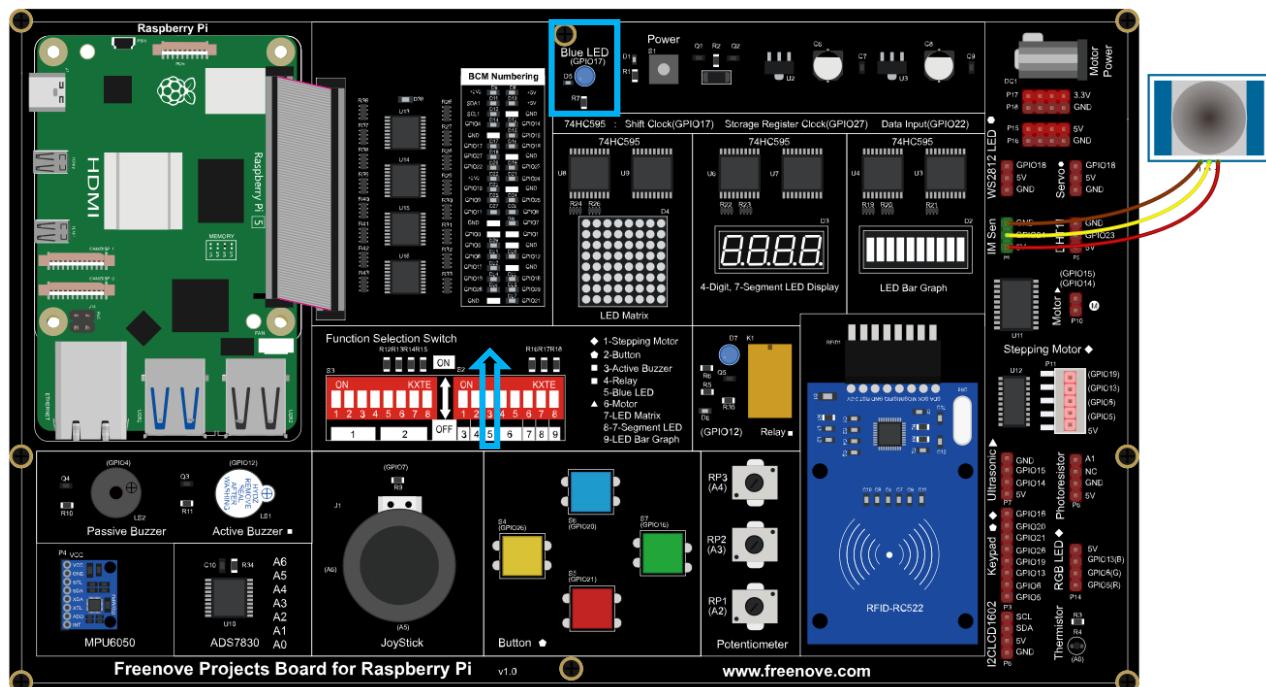


## Circuit

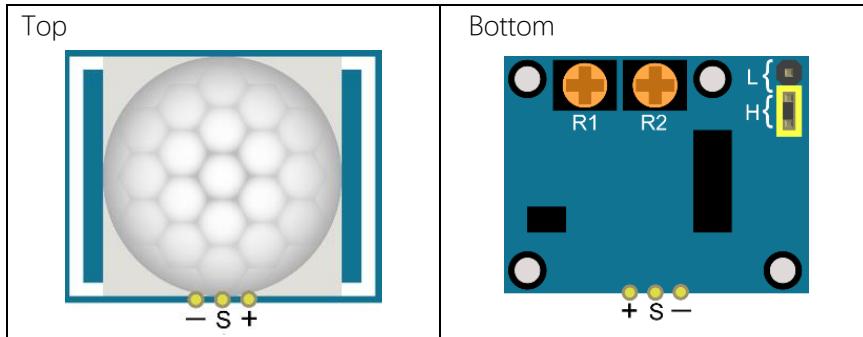
Schematic diagram



Hardware connection.



### How to use this sensor?



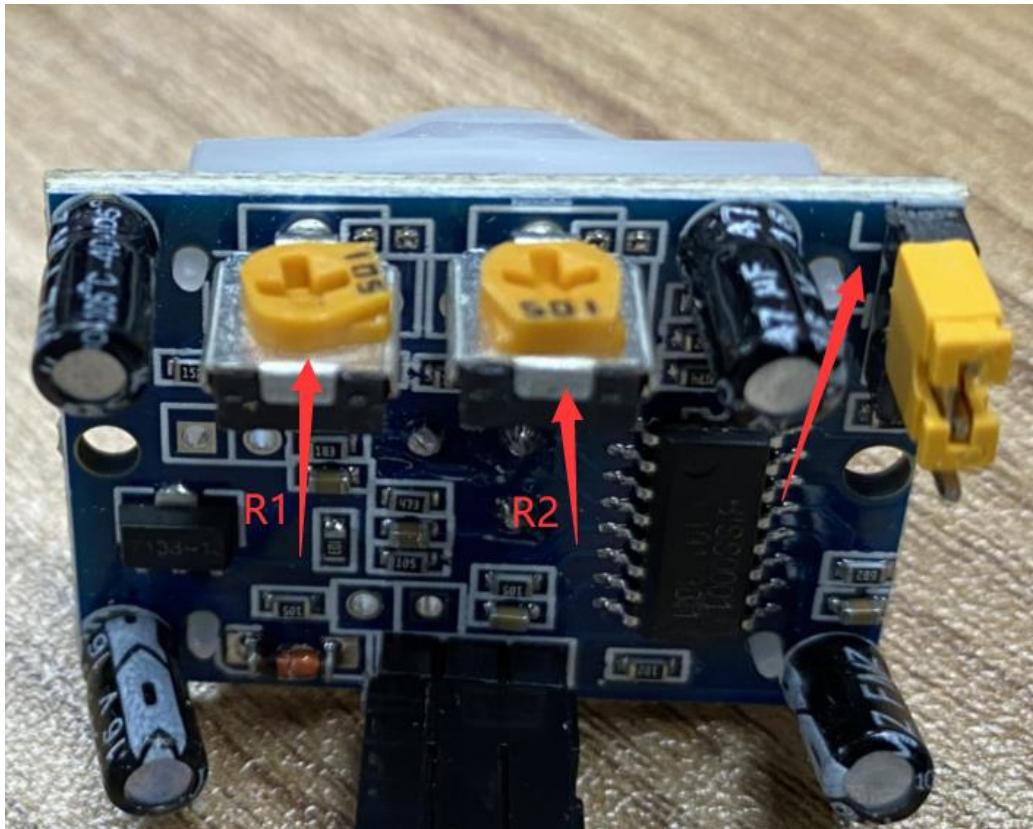
#### Description:

1. You can choose non-repeatable trigger modes or repeatable modes.  
L: non-repeatable trigger mode. The module outputs high level after sensing a body, then when the delay time is over, the module will output low level. During high-level time, the sensor no longer actively senses bodies.  
H: repeatable trigger mode. The distinction from the L mode is that it can sense a body until that body leaves. After this, it starts to time and output low level after delaying T time.
2. R1 is used to adjust HIGH level lasting time when sensor detects human motion, 1.2s~320s.
3. R2 is used to adjust the maximum distance the sensor can detect, 3~5m.

Here we connect L and adjust R1 and R2 like below to do this project.

Put your hand close and away from the sensor slowly. Observe the LED in previous circuit.

It needs some time between two detections.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this section, we will utilize an infrared motion sensor to control an LED, where the sensor will function as a motion-activated switch. The code is quite analogous to our previous project "Push Button Switch and LED." However, unlike the button which outputs a low signal when pressed, the infrared motion sensor outputs a high signal upon detecting motion. Consequently, when the sensor outputs a high level, the LED will illuminate or turn off.

### Sketch\_21\_1\_InfraredSensor

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_21_1_InfraredSensor
```

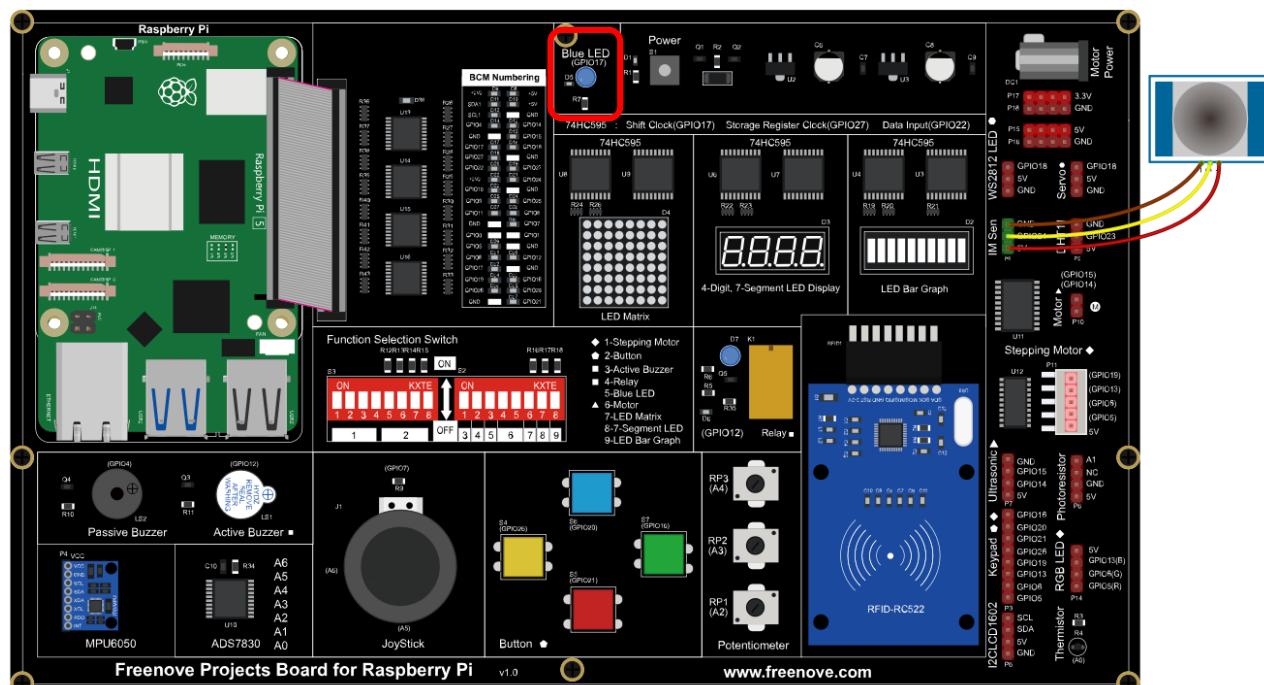
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_21_1_InfraredSensor
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_21_1_InfraredSensor $
```

Enter the command to run the code.

```
jbang SenseLED.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_21_1_InfraredSensor
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_21_1_InfraredSensor $ jbang SenseLED.java
```

Once the code is running, you can observe whether the LED turns on or off by moving away from or closer to the infrared motion sensor.



The terminal will continuously display the LED status, as shown below:

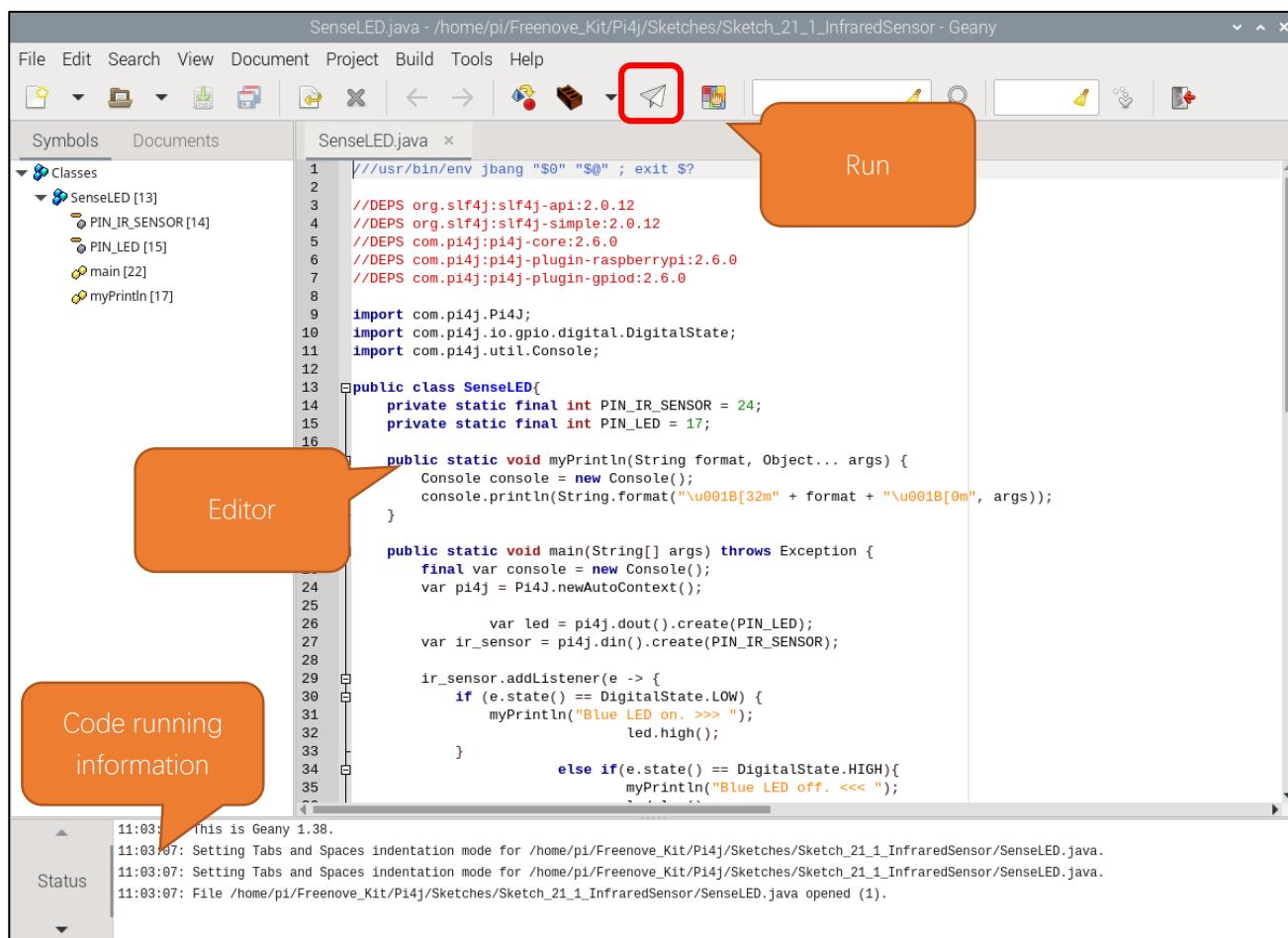
```
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Blue LED on. >>>
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Blue LED off. <<<
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Blue LED on. >>>
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Blue LED off. <<<
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Blue LED on. >>>
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Blue LED off. <<<
[Pi4J.RUNTIME-1] INFO com.pi4j.util.Console - Blue LED on. >>>
```

Press Ctrl+C to exit the program.

You can run the following command to open the code with Geany to view and edit it.

geany SenseLED.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```
1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8
9 import com.pi4j.Pi4J;
10 import com.pi4j.io.gpio.digital.DigitalState;
11 import com.pi4j.util.Console;
12
13 public class SenseLED {
14     private static final int PIN_IR_SENSOR =
```

```
15     private static final int PIN_LED = 17;
16
17     public static void myPrintln(String format, Object... args) {
18         Console console = new Console();
19         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
20     }
21
22     public static void main(String[] args) throws Exception {
23         final var console = new Console();
24         var pi4j = Pi4J.newAutoContext();
25
26         var led = pi4j.dout().create(PIN_LED);
27         var ir_sensor = pi4j.din().create(PIN_IR_SENSOR);
28
29         ir_sensor.addListener(e -> {
30             if (e.state() == DigitalState.LOW) {
31                 myPrintln("Blue LED on. >>> ");
32                 led.high();
33             } else if (e.state() == DigitalState.HIGH) {
34                 myPrintln("Blue LED off. <<< ");
35                 led.low();
36             }
37         });
38
39         try {
40             while (true) {
41                 Thread.sleep(500);
42             }
43         } finally {
44             pi4j.shutdown();
45         }
46     }
47 }
```



# Chapter 22 Ultrasonic Ranging

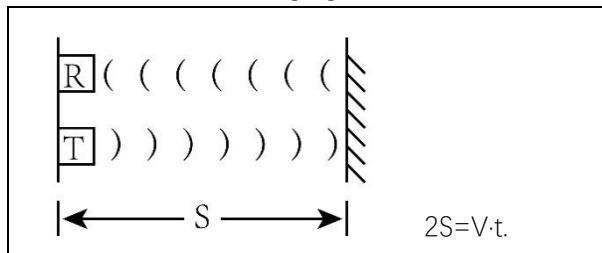
In this chapter, we learn a module taht use ultrasonic to measure distance, HC SR04.

## Project 22.1 Ultrasonic Ranging

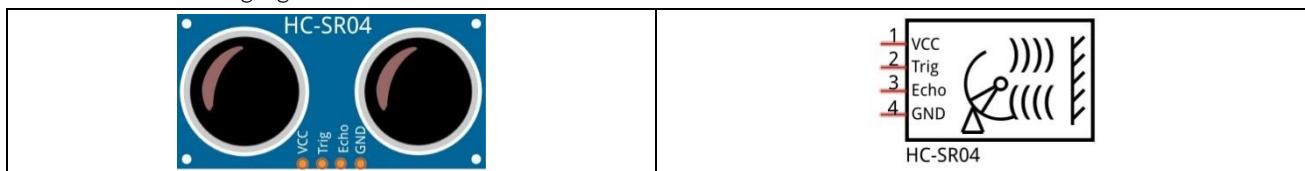
In this project, we use ultrasonic ranging module to measure distance, and print out the data in the terminal.

### Component Knowledge

The Ultrasonic Ranging Module uses the principle that ultrasonic waves will be reflected when they encounter any obstacles. This is possible by counting the time interval between when the ultrasonic wave is transmitted to when the ultrasonic wave reflects back after encountering an obstacle. Time interval counting will end after an ultrasonic wave is received, and the time difference (delta) is the total time of the ultrasonic wave's journey from being transmitted to being received. Because the speed of sound in air is a constant, and is about  $v=340\text{m/s}$ , we can calculate the distance between the Ultrasonic Ranging Module and the obstacle:  $s=vt/2$ .



The HC-SR04 Ultrasonic Ranging Module integrates both an ultrasonic transmitter and a receiver. The transmitter is used to convert electrical signals (electrical energy) into high frequency (beyond human hearing) sound waves (mechanical energy) and the function of the receiver is opposite of this. The picture and the diagram of the HC SR04 Ultrasonic Ranging Module are shown below:



Pin description:

VCC	power supply pin
Trig	trigger pin
Echo	Echo pin
GND	GND

**Technical specs:**

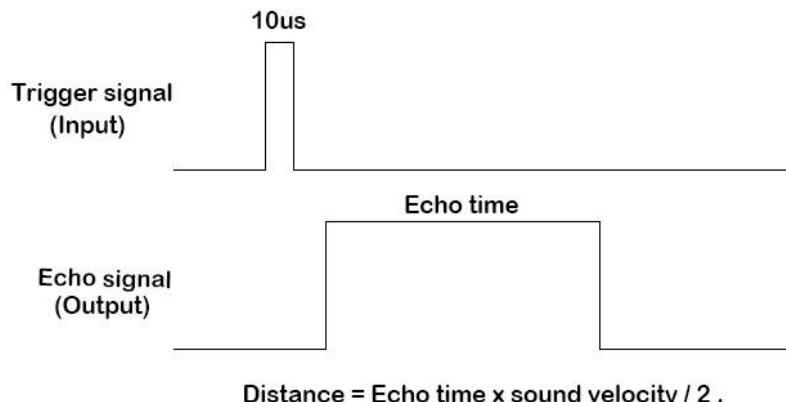
Working voltage: 5V

Working current: 12mA

Minimum measured distance: 2cm

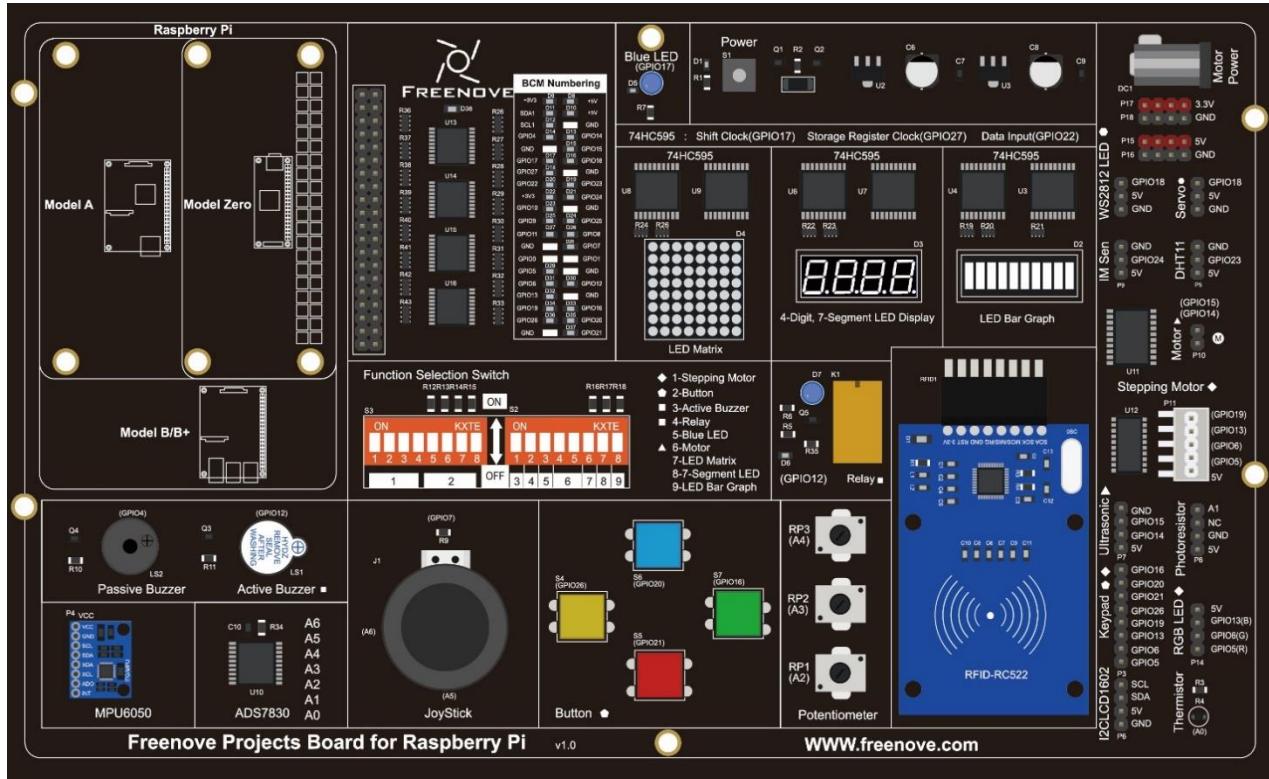
Maximum measured distance: 200cm

Instructions for Use: output a high-level pulse in Trig pin lasting for least 10uS, the module begins to transmit ultrasonic waves. At the same time, the Echo pin is pulled up. When the module receives the returned ultrasonic waves from encountering an obstacle, the Echo pin will be pulled down. The duration of high level in the Echo pin is the total time of the ultrasonic wave from transmitting to receiving,  $s=vt/2$ . This is done constantly.

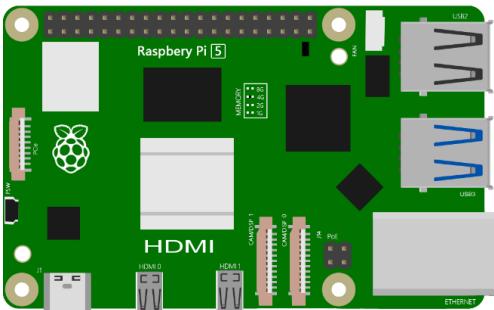


## Component List

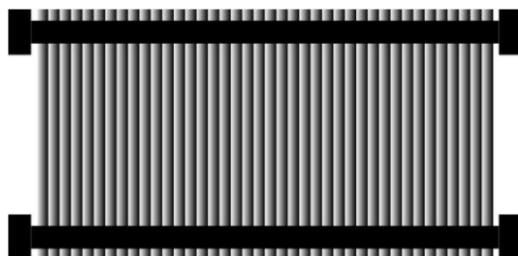
Freenove Projects Board for Raspberry Pi



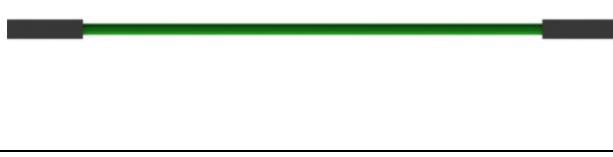
Raspberry Pi



GPIO Ribbon Cable



Jumper Wire

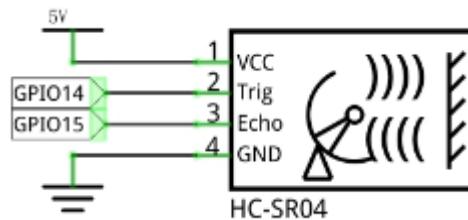


HC SR04



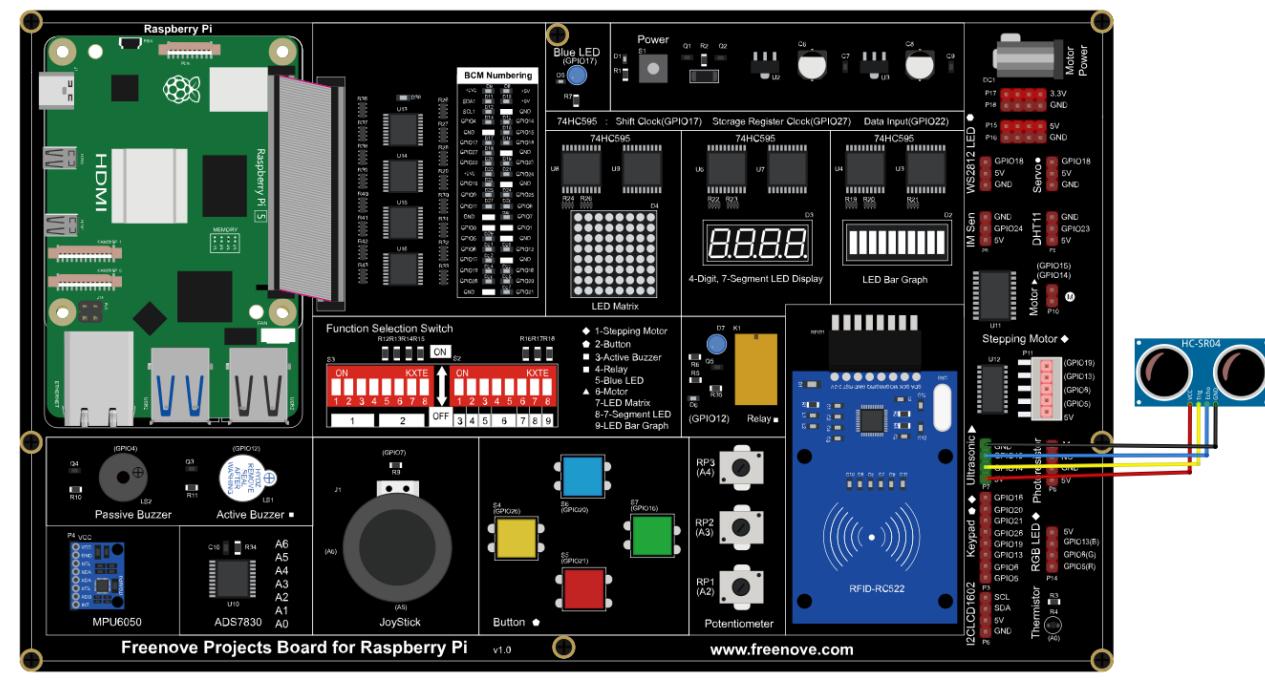
## Circuit

Schematic diagram



Hardware connection.

After running the program, hold an object in front of the sensor and change their distance.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this chapter, we will learn the usage of the ultrasonic sensor.

### Sketch\_22\_UltrasonicRanging

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_22_UltrasonicRanging
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_22_UltrasonicRanging
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_22_UltrasonicRanging $
```

Enter the command to run the code.

```
jbang UltrasonicRanging.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_22_UltrasonicRanging
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_22_UltrasonicRanging $ jbang UltrasonicRanging.java
```

After running the code, the Raspberry Pi will continue to obtain the distance values of the ultrasonic module and print them on the terminal interface.

```
pi@raspberrypi: ~ /Freenove_Kit/Pi4j/Sketches/Sketch_22_UltrasonicRanging
File Edit Tabs Help
[main] INFO com.pi4j.util.Console - Distance: 298.42cm
[main] INFO com.pi4j.util.Console - Distance: 306.04cm
[main] INFO com.pi4j.util.Console - Distance: 15.88cm
[main] INFO com.pi4j.util.Console - Distance: 15.85cm
[main] INFO com.pi4j.util.Console - Distance: 13.18cm
[main] INFO com.pi4j.util.Console - Distance: 17.53cm
[main] INFO com.pi4j.util.Console - Distance: 17.89cm
[main] INFO com.pi4j.util.Console - Distance: 298.10cm
[main] INFO com.pi4j.util.Console - Distance: 305.95cm
[main] INFO com.pi4j.util.Console - Distance: 298.10cm
[main] INFO com.pi4j.util.Console - Distance: 306.00cm
[main] INFO com.pi4j.util.Console - Distance: 124.68cm
[main] INFO com.pi4j.util.Console - Distance: 15.48cm
[main] INFO com.pi4j.util.Console - Distance: 11.75cm
[main] INFO com.pi4j.util.Console - Distance: 12.14cm
[main] INFO com.pi4j.util.Console - Distance: 11.51cm
[main] INFO com.pi4j.util.Console - Distance: 15.02cm
[main] INFO com.pi4j.util.Console - Distance: 16.46cm
[main] INFO com.pi4j.util.Console - Distance: 18.54cm
[main] INFO com.pi4j.util.Console - Distance: 298.03cm
[main] INFO com.pi4j.util.Console - Distance: 306.02cm
[main] INFO com.pi4j.util.Console - Distance: 298.11cm
```

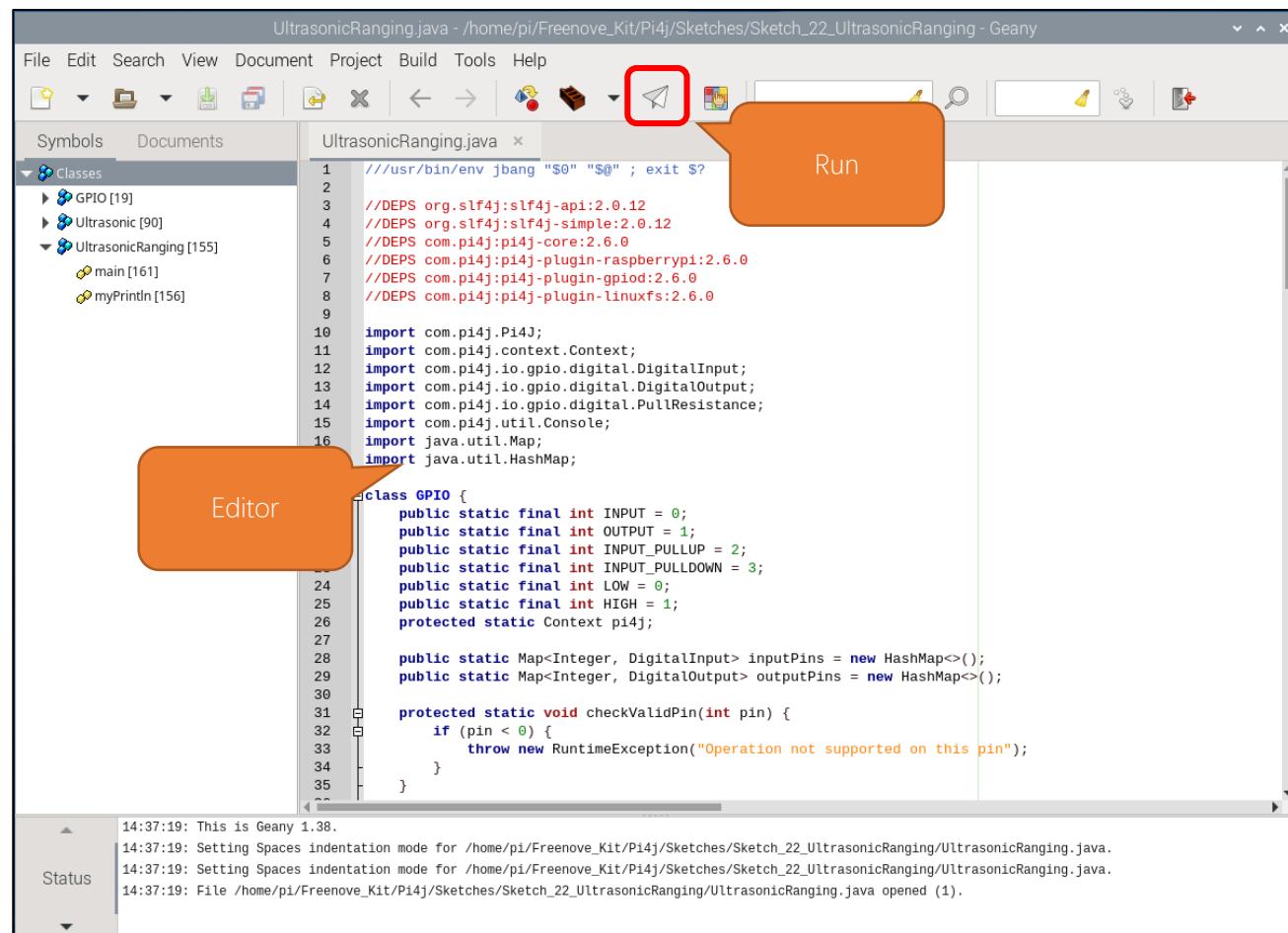
Press Ctrl+C to exit the program.

```
[main] INFO com.pi4j.util.Console - Distance: 306.05cm
[main] INFO com.pi4j.util.Console - Distance: 297.77cm
[main] INFO com.pi4j.util.Console - Distance: 306.05cm
[main] INFO com.pi4j.util.Console - Distance: 297.93cm
[main] INFO com.pi4j.util.Console - Distance: 306.04cm
^C[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Shutting down Pi4J context/runtime...
[pi4j-shutdown] INFO com.pi4j.plugin.gpio.provider.gpio.digital.GpioDDigitalInput - Shutdown input listener for DIN-15
[pi4j-shutdown] INFO com.pi4j.util.ExecutorPool - Shutting down executor pool Pi4J.RUNTIME
[pi4j-shutdown] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully shutdown. Dispatching shutdown event.
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_22_UltrasonicRanging $
```

You can run the following command to open the code with Geany to view and edit it.

### geany UltrasonicRanging.java

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 //usr/bin/env jbang "$0" "$@" ; exit $?
2
3 //DEPS org.slf4j:slf4j-api:2.0.12
4 //DEPS org.slf4j:slf4j-simple:2.0.12
5 //DEPS com.pi4j:pi4j-core:2.6.0
6 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.6.0
7 //DEPS com.pi4j:pi4j-plugin-gpiod:2.6.0
8 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.6.0
9
10 import com.pi4j.Pi4J;
11 import com.pi4j.context.Context;
12 import com.pi4j.io.gpio.digital.DigitalInput;
13 import com.pi4j.io.gpio.digital.DigitalOutput;
14 import com.pi4j.io.gpio.digital.PullResistance;

```

```
15 import com.pi4j.util.Console;
16 import java.util.Map;
17 import java.util.HashMap;
18
19 class GPIO {
...
    ....
88 }
89
90 class Ultrasonic {
...
    ....
145 }
146
147 public class UltrasonicRanging {
148     public static void myPrintln(String format, Object... args) {
149         Console console = new Console();
150         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
151     }
152
153     public static void main(String[] args) throws Exception {
154         try {
155             GPIO.pi4j = Pi4J.newAutoContext();
156             Ultrasonic ultrasonic = new Ultrasonic(14, 15);
157             while (true) {
158                 float distance = ultrasonic.measureDistance();
159                 if (distance != -1) {
160                     myPrintln("Distance: %.2fcm", distance);
161                 } else {
162                     myPrintln("No object detected within the maximum distance.");
163                 }
164                 Thread.sleep(100);
165             }
166         } catch (InterruptedException e) {
167             myPrintln("Interrupted. Exiting...");
168         } finally {
169             if (GPIO.pi4j != null) {
170                 GPIO.pi4j.shutdown();
171             }
172         }
173     }
174 }
```

Re-encapsulate the GPIO functions using the Pi4J library, with these functions emulating the classic usage patterns of Arduino. This is done to ensure compatibility with the upcoming Ultrasonic class, allowing the Raspberry Pi to easily obtain distance data from ultrasonic modules. If you are interested in this code, please review it, as we will include detailed comments within the code.

```
class GPIO {  
    ....  
}  
  
class Ultrasonic {  
    ....  
}
```

Initialize the Pi4J context and assign it to GPIO.pi4.

Initialize the Ultrasonic class and associate it with GPIO14 and GPIO15.

```
GPIO.pi4j = Pi4J.newAutoContext();  
Ultrasonic ultrasonic = new Ultrasonic(14, 15);
```

Obtain the ultrasonic distance data every 100 milliseconds and display them on the terminal interface.

```
while (true) {  
    float distance = ultrasonic.measureDistance();  
    if (distance != -1) {  
        myPrintln("Distance: %.2fcm", distance);  
    } else {  
        myPrintln("No object detected within the maximum distance.");  
    }  
    Thread.sleep(100);  
}
```

At the end of the code, release the resources.

```
finally {  
    if (GPIO.pi4j != null) {  
        GPIO.pi4j.shutdown();  
    }  
}
```



# Chapter 23 Attitude Sensor MPU6050

In this chapter, we will learn about a MPU6050 Attitude sensor, which integrates an Accelerometer and Gyroscope.

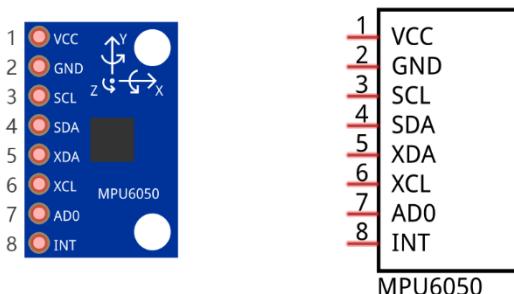
## Project 23.1 Read an MPU6050 Sensor Module

In this project, we will read Acceleration and Gyroscope Data of the MPU6050 Sensor.

### Component knowledge

#### MPU6050

MPU6050 Sensor Module is a complete 6-axis Motion Tracking Device. It combines a 3-axis Gyroscope, a 3-axis Accelerometer and a DMP (Digital Motion Processor) all in a small package. The settings of the Accelerometer and Gyroscope of MPU6050 can be changed. A precision wide range digital temperature sensor is also integrated to compensate data readings for changes in temperature, and temperature values can also be read. The MPU6050 Module follows the I2C communication protocol and the default address is 0x68.



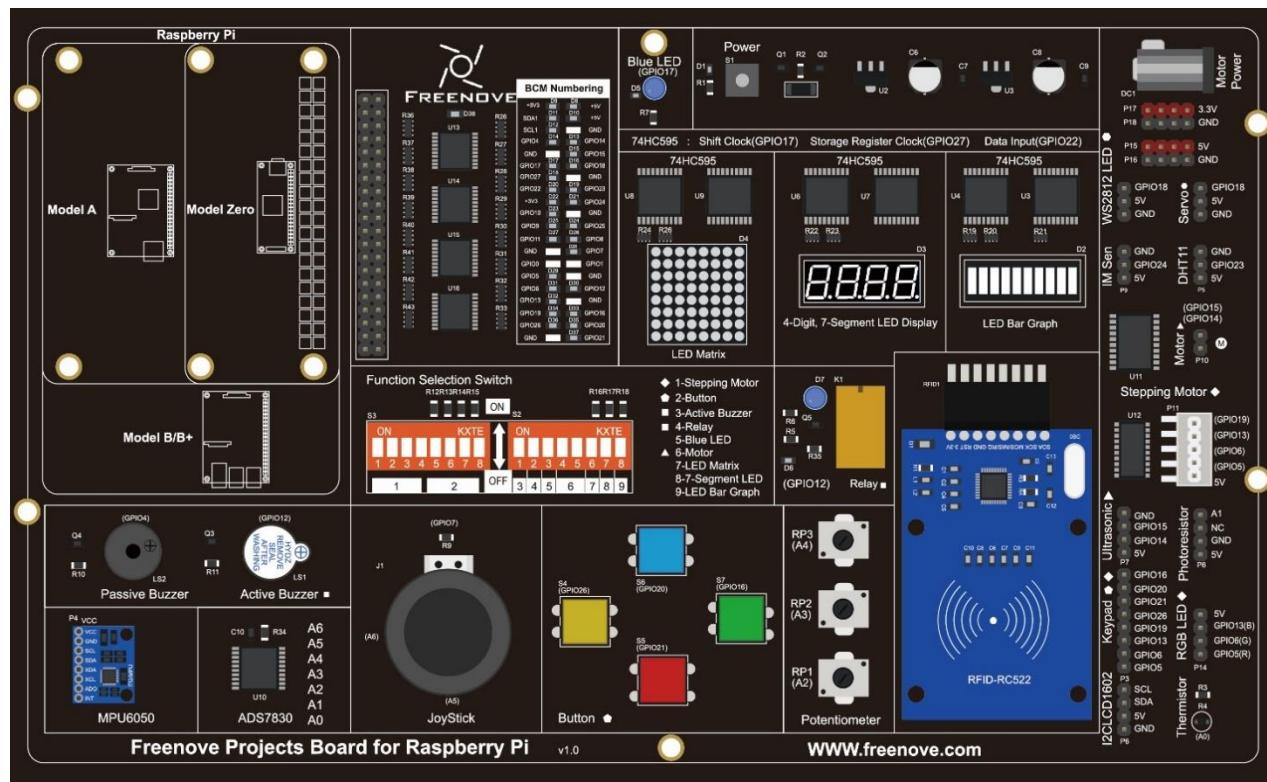
The port description of the MPU6050 Module is as follows:

Pin name	Pin number	Description
VCC	1	Positive pole of power supply with voltage 5V
GND	2	Negative pole of power supply
SCL	3	I2C communication clock pin
SDA	4	I2C communication data pin
XDA	5	I2C host data pin which can be connected to other devices.
XCL	6	I2C host clock pin which can be connected to other devices.
AD0	7	I2C address bit control pin. Low level: the device address is 0x68 High level: the device address is 0x69
INT	8	Output interrupt pin

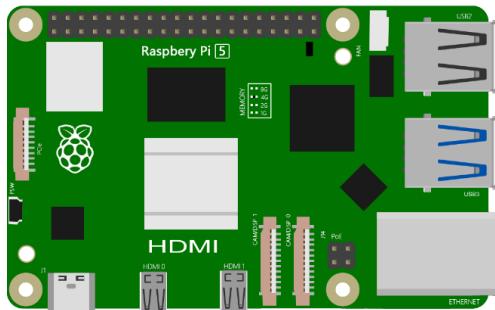
For more detail, please refer to the MPU6050 datasheet.

## Component List

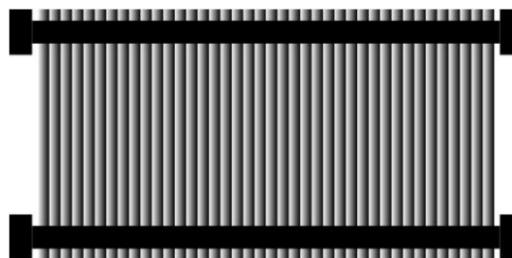
Freenove Projects Board for Raspberry Pi



## Raspberry Pi



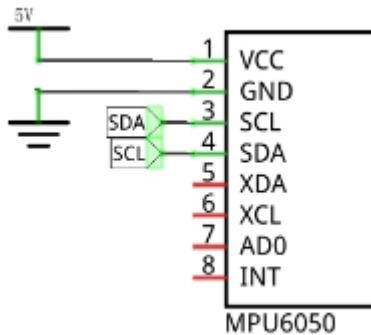
## GPIO Ribbon Cable





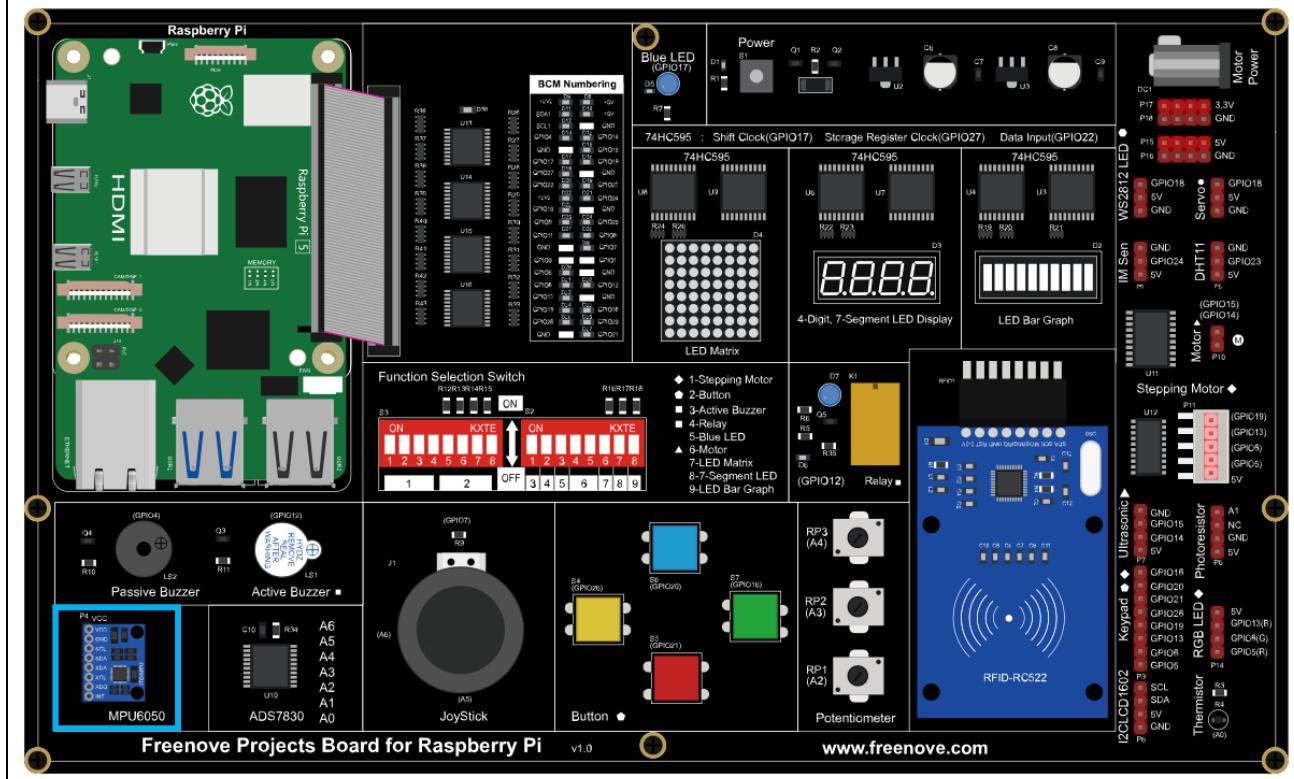
## Circuit

Schematic diagram



Hardware connection.

After running the program, hold the board and turn it over to observe the changes in the running results.



If you have any concerns, please send an email to: [support@freenove.com](mailto:support@freenove.com)

## Sketch

In this chapter, we will learn to obtain MPU6050 data and print them.

### Sketch\_23\_MP6050

First, enter where the project is located:

```
cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_23_MP6050
```

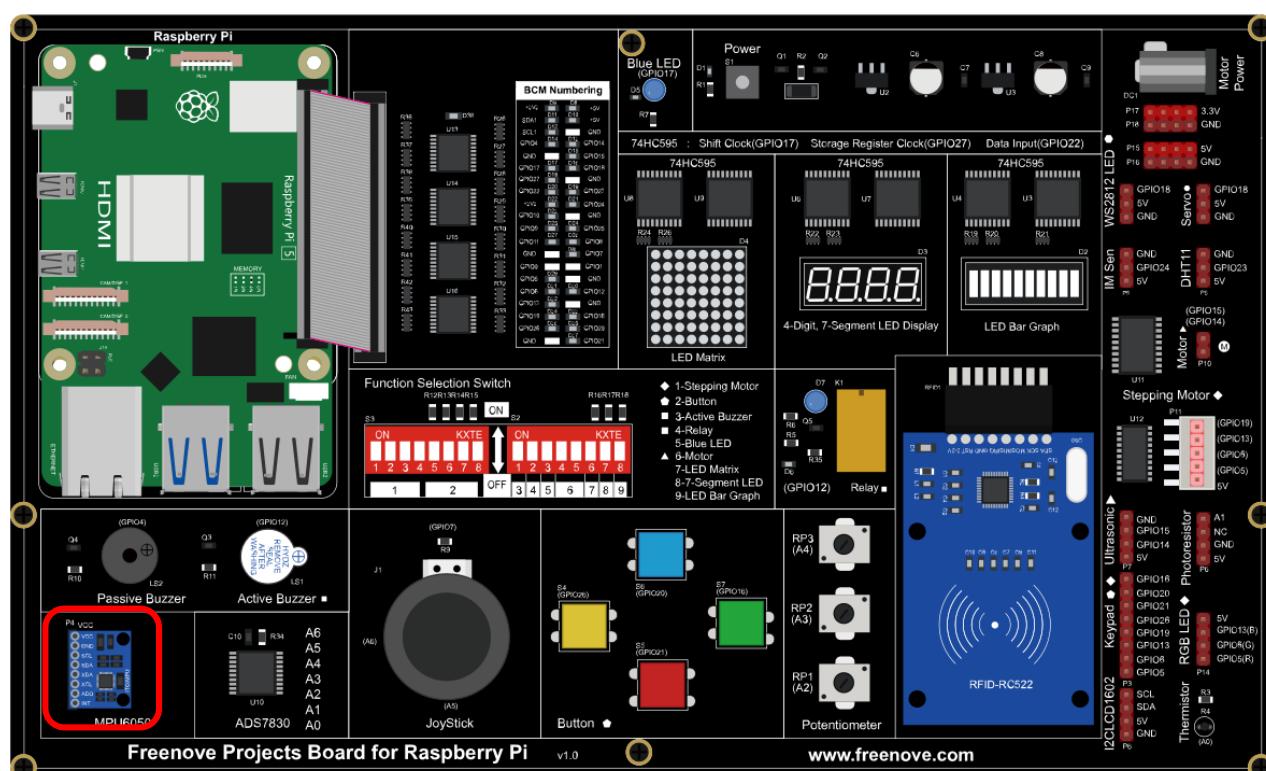
```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_23_MP6050
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_23_MP6050 $
```

Enter the command to run the code.

```
jbang MP6050RAW.java
```

```
pi@raspberrypi:~ $ cd ~/Freenove_Kit/Pi4j/Sketches/Sketch_23_MP6050
pi@raspberrypi:~/Freenove_Kit/Pi4j/Sketches/Sketch_23_MP6050 $ jbang MP6050RAW.java
```

When the code is running, pick up the entire board with and make any movements such as shaking it left and right, turning it upside down, etc. You can observe the changes in data on the terminal interface.



```
i; name=RaspberryPi Platform; priority=5; class=com.pi4j.plugin.raspberrypi.platform.RaspberryPiPlatform]
[main] INFO com.pi4j.runtime.impl.DefaultRuntime - Pi4J context/runtime successfully initialized.
[main] INFO com.pi4j.util.Console - WHO AM I: 0x68
[main] INFO com.pi4j.util.Console - MPU6050 device identified correctly.
[main] INFO com.pi4j.util.Console - a/g: 1288 160 15924 -143 7 -125
[main] INFO com.pi4j.util.Console - a/g: 0.08 g 0.01 g 0.97 g -1.09 d/s 0.05 d/s -0.95 d/s

[main] INFO com.pi4j.util.Console - a/g: 1364 184 16024 -155 -6 -126
[main] INFO com.pi4j.util.Console - a/g: 0.08 g 0.01 g 0.98 g -1.18 d/s -0.05 d/s -0.96 d/s

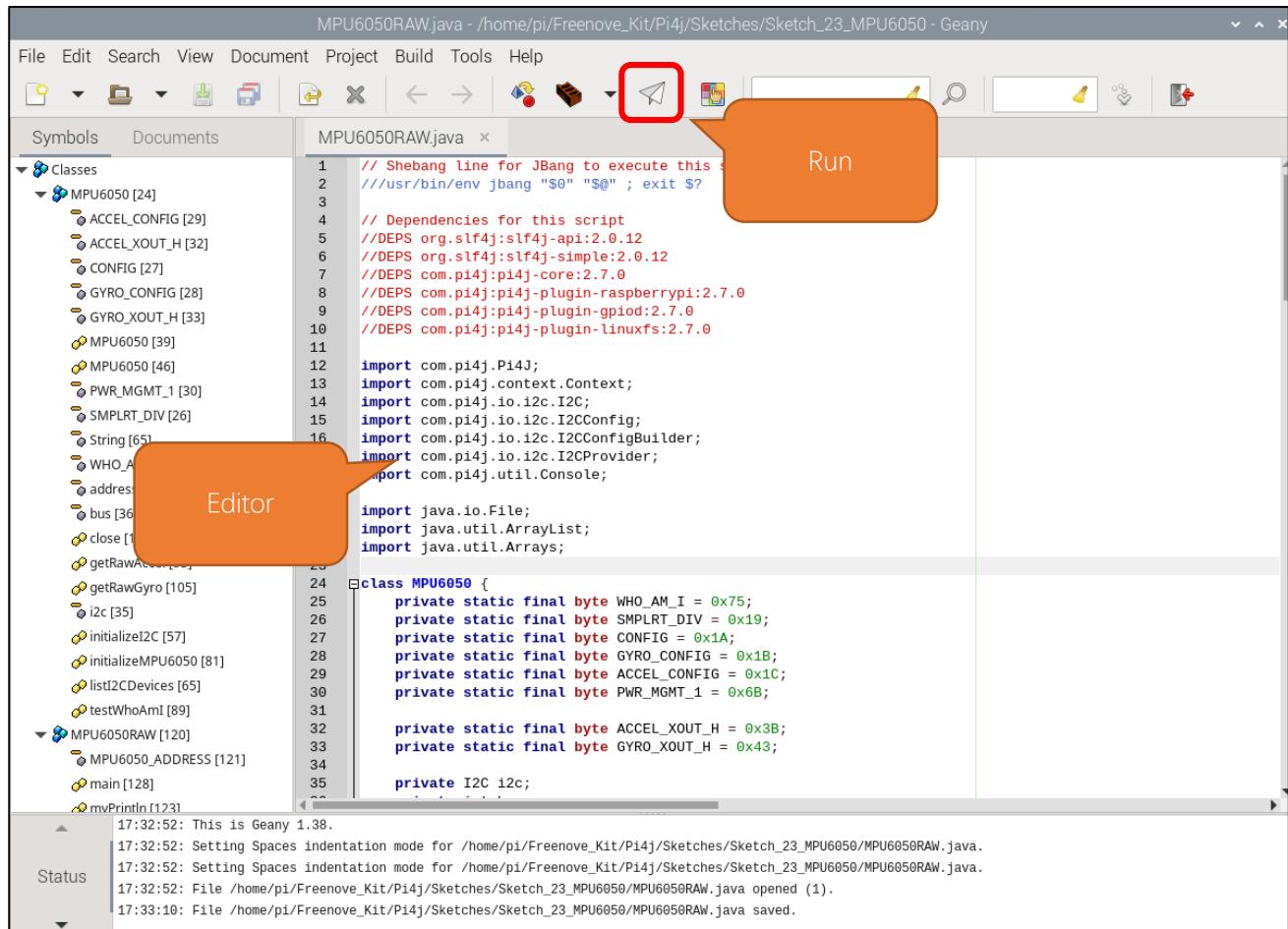
[main] INFO com.pi4j.util.Console - a/g: 1328 240 15880 -168 -26 -131
[main] INFO com.pi4j.util.Console - a/g: 0.08 g 0.01 g 0.97 g -1.28 d/s -0.20 d/s -1.00 d/s
```

Press Ctrl+C to exit the program.

You can run the following command to open the code with Geany to view and edit it.

**geany MPU6050RAW.java**

Click the icon to run the code.



If the code fails to run, please check [Geany Configuration](#).

The following is program code:

```

1 // Shebang line for JBang to execute this script directly
2 //!/usr/bin/env jbang "$0" "$@" ; exit $?
3
4 // Dependencies for this script
5 //DEPS org.slf4j:slf4j-api:2.0.12
6 //DEPS org.slf4j:slf4j-simple:2.0.12
7 //DEPS com.pi4j:pi4j-core:2.7.0
8 //DEPS com.pi4j:pi4j-plugin-raspberrypi:2.7.0
9 //DEPS com.pi4j:pi4j-plugin-gpiod:2.7.0
10 //DEPS com.pi4j:pi4j-plugin-linuxfs:2.7.0
11
12 import com.pi4j.Pi4J;
13 import com.pi4j.context.Context;
14 import com.pi4j.io.i2c.I2C;
15 import com.pi4j.io.i2c.I2CConfig;
16 import com.pi4j.io.i2c.I2CConfigBuilder;
17 import com.pi4j.io.i2c.I2CProvider;
18 import com.pi4j.util.Console;
19
20 import java.io.File;
21 import java.util.ArrayList;
22 import java.util.Arrays;
23
24 class MPU6050 {
25     private static final byte WHO_AM_I = 0x75;
26     private static final byte SMPLRT_DIV = 0x19;
27     private static final byte CONFIG = 0x1A;
28     private static final byte GYRO_CONFIG = 0x1B;
29     private static final byte ACCEL_CONFIG = 0x1C;
30     private static final byte PWR_MGMT_1 = 0x6B;
31
32     private static final byte ACCEL_XOUT_H = 0x3B;
33     private static final byte GYRO_XOUT_H = 0x43;
34
35     private I2C i2c;
36 }
```

```
15 import com.pi4j.io.i2c.I2CConfig;
16 import com.pi4j.io.i2c.I2CConfigBuilder;
17 import com.pi4j.io.i2c.I2CProvider;
18 import com.pi4j.util.Console;
19
20 import java.io.File;
21 import java.util.ArrayList;
22 import java.util.Arrays;
23
24 class MPU6050 {
25     private static final byte WHO_AM_I = 0x75;
26     private static final byte SMPLRT_DIV = 0x19;
27     private static final byte CONFIG = 0x1A;
28     private static final byte GYRO_CONFIG = 0x1B;
29     private static final byte ACCEL_CONFIG = 0x1C;
30     private static final byte PWR_MGMT_1 = 0x6B;
31     private static final byte ACCEL_XOUT_H = 0x3B;
32     private static final byte GYRO_XOUT_H = 0x43;
33
34     private I2C i2c;
35     private int bus;
36     private int address;
37
38     public MPU6050(int bus, int address) {
39         this.bus = bus;
40         this.address = address;
41         initializeI2C();
42         initializeMPU6050();
43     }
44
45     public MPU6050(String busString, int address) {
46         this.address = address;
47         try {
48             this.bus = Integer.parseInt(busString.split("i2c-")[1]);
49         } catch (Exception e) {
50             this.bus = 1;
51         }
52         initializeI2C();
53         initializeMPU6050();
54     }
55
56     private void initializeI2C() {
57         Context pi4j = Pi4J.newAutoContext();
58         I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
```

```
59     I2CConfigBuilder i2cConfigBuilder = I2C.newConfigBuilder(pi4j).bus(bus);
60     I2CConfig i2cConfig = i2cConfigBuilder.device(address).build();
61     this.i2c = i2CProvider.create(i2cConfig);
62 }
63
64     public static String[] listI2CDevices() {
65         ArrayList<String> devs = new ArrayList<>();
66         File dir = new File("/dev");
67         File[] files = dir.listFiles();
68         if (files != null) {
69             for (File file : files) {
70                 if (file.getName().startsWith("i2c-")) {
71                     devs.add(file.getName());
72                 }
73             }
74         }
75         String[] tmp = devs.toArray(new String[devs.size()]);
76         Arrays.sort(tmp);
77         return tmp;
78     }
79
80     private void initializeMPU6050() {
81         i2c.writeRegister(PWR_MGMT_1, 0x01);
82         i2c.writeRegister(SMPLRT_DIV, 0x00);
83         i2c.writeRegister(CONFIG, 0x00);
84         i2c.writeRegister(GYRO_CONFIG, 0x08);
85         i2c.writeRegister(ACCEL_CONFIG, 0x00);
86     }
87
88     public byte testWhoAmI() {
89         byte[] whoAmI = new byte[1];
90         i2c.readRegister(WHO_AM_I, whoAmI);
91         return whoAmI[0];
92     }
93
94     public int[] getRawAccel() {
95         int[] data = new int[3];
96         byte[] buffer = new byte[6];
97         i2c.readRegister(ACCEL_XOUT_H, buffer, buffer.length);
98         data[0] = (buffer[0] << 8) | (buffer[1] & 0xFF);
99         data[1] = (buffer[2] << 8) | (buffer[3] & 0xFF);
100        data[2] = (buffer[4] << 8) | (buffer[5] & 0xFF);
101        return data;
102    }
```

```
103
104     public int[] getRawGyro() {
105         int[] data = new int[3];
106         byte[] buffer = new byte[6];
107         i2c.readRegister(GYRO_XOUT_H, buffer, buffer.length);
108         data[0] = (buffer[0] << 8) | (buffer[1] & 0xFF);
109         data[1] = (buffer[2] << 8) | (buffer[3] & 0xFF);
110         data[2] = (buffer[4] << 8) | (buffer[5] & 0xFF);
111         return data;
112     }
113
114     public void close() {
115         i2c.close();
116     }
117 }
118
119 public class MPU6050RAW {
120     public static final int MPU6050_ADDRESS = 0x68;
121
122     public static void myPrintln(String format, Object... args) {
123         Console console = new Console();
124         console.println(String.format("\u001B[32m" + format + "\u001B[0m", args));
125     }
126
127     public static void main(String[] args) {
128         MPU6050 mpu = null;
129         try {
130             mpu = new MPU6050(MPU6050.listI2CDevices()[0], MPU6050_ADDRESS);
131
132             // Test WHO AM I register
133             int whoAmI = mpu.testWhoAmI();
134             myPrintln("WHO AM I: 0x%02X", whoAmI);
135             if (whoAmI == MPU6050_ADDRESS) {
136                 myPrintln("MPU6050 device identified correctly.");
137             } else {
138                 myPrintln("Failed to identify MPU6050 device. Got: 0x%02X", whoAmI);
139             }
140
141             while (true) {
142                 int[] accel = mpu.getRawAccel();
143                 int[] gyro = mpu.getRawGyro();
144                 myPrintln("a/g: %8d %8d %8d      %8d %10d %10d",
145                         accel[0], accel[1], accel[2], gyro[0], gyro[1], gyro[2]);
146                 myPrintln("a/g: %.2f g  %.2f g  %.2f g   %.2f d/s  %.2f d/s  %.2f d/s\n",
147                         accel[0], accel[1], accel[2], gyro[0], gyro[1], gyro[2]);
148             }
149         } catch (Exception e) {
150             e.printStackTrace();
151         }
152     }
153 }
```

```

147             (float)accel[0]/16384, (float)accel[1]/16384, (float)accel[2]/16384,
148             (float)gyro[0]/131, (float)gyro[1]/131, (float)gyro[2]/131);
149             Thread.sleep(300);
150         }
151     } catch (InterruptedException e) {
152         e.printStackTrace();
153         Thread.currentThread().interrupt();
154     } finally {
155         if (mpu != null) {
156             mpu.close();
157         }
158     }
159 }
160 }
```

Define the commonly used registers of MPU6050.

```

private static final byte WHO_AM_I = 0x75;
private static final byte SMPLRT_DIV = 0x19;
private static final byte CONFIG = 0x1A;
private static final byte GYRO_CONFIG = 0x1B;
private static final byte ACCEL_CONFIG = 0x1C;
private static final byte PWR_MGMT_1 = 0x6B;
private static final byte ACCEL_XOUT_H = 0x3B;
private static final byte GYRO_XOUT_H = 0x43;
```

Initialize the I2C interface of the Raspberry Pi.

```

private void initializeI2C() {
    Context pi4j = Pi4J.newAutoContext();
    I2CProvider i2CProvider = pi4j.provider("linuxfs-i2c");
    I2CConfigBuilder i2cConfigBuilder = I2C.newConfigBuilder(pi4j).bus(bus);
    I2CConfig i2cConfig = i2cConfigBuilder.device(address).build();
    this.i2c = i2CProvider.create(i2cConfig);
}
```

Configure MPU6050 so that it can work properly.

```

private void initializeMPU6050() {
    i2c.writeRegister(PWR_MGMT_1, 0x01);
    i2c.writeRegister(SMPLRT_DIV, 0x00);
    i2c.writeRegister(CONFIG, 0x00);
    i2c.writeRegister(GYRO_CONFIG, 0x08);
    i2c.writeRegister(ACCEL_CONFIG, 0x00);
}
```

Get the I2C address of MPU6050. This is only used for testing.

```
public byte testWhoAmI() {
    byte[] whoAmI = new byte[1];
    i2c.readRegister(WHO_AM_I, whoAmI);
    return whoAmI[0];
}
```

Get raw acceleration data.

```
public int[] getRawAccel() {
    int[] data = new int[3];
    byte[] buffer = new byte[6];
    i2c.readRegister(ACCEL_XOUT_H, buffer, buffer.length);
    data[0] = (buffer[0] << 8) | (buffer[1] & 0xFF);
    data[1] = (buffer[2] << 8) | (buffer[3] & 0xFF);
    data[2] = (buffer[4] << 8) | (buffer[5] & 0xFF);
    return data;
}
```

Get raw gyroscope data.

```
public int[] getRawGyro() {
    int[] data = new int[3];
    byte[] buffer = new byte[6];
    i2c.readRegister(GYRO_XOUT_H, buffer, buffer.length);
    data[0] = (buffer[0] << 8) | (buffer[1] & 0xFF);
    data[1] = (buffer[2] << 8) | (buffer[3] & 0xFF);
    data[2] = (buffer[4] << 8) | (buffer[5] & 0xFF);
    return data;
}
```

Define the I2C address of MPU6050.

```
public static final int MPU6050_ADDRESS = 0x68;
```

Get the I2C address from the MPU6050 register and determine whether it is consistent with the predefined address.

```
// Test WHO AM I register
int whoAmI = mpu.testWhoAmI();
myPrintln("WHO AM I: 0x%02X", whoAmI);
if (whoAmI == MPU6050_ADDRESS) {
    myPrintln("MPU6050 device identified correctly.");
} else {
    myPrintln("Failed to identify MPU6050 device. Got: 0x%02X", whoAmI);
}
```

Get the raw data of the accelerometer and gyroscope of MPU6050, convert them and print them out.

```
while (true) {
    int[] accel = mpu.getRawAccel();
    int[] gyro = mpu.getRawGyro();
    myPrintln("a/g: %8d %8d %8d      %8d %10d %10d",
              accel[0], accel[1], accel[2], gyro[0], gyro[1], gyro[2]);
    myPrintln("a/g: %.2f g  %.2f g  %.2f g  %.2f d/s  %.2f d/s  %.2f d/s\n",
              (float)accel[0]/16384, (float)accel[1]/16384, (float)accel[2]/16384,
              (float)gyro[0]/131, (float)gyro[1]/131, (float)gyro[2]/131);
    Thread.sleep(300);
}
```

Thread exception capture ensures that the code runs normally.

```
catch (InterruptedException e) {
    e.printStackTrace();
    Thread.currentThread().interrupt();
}
```

When terminating the execution of the code, shut down the MPU6050 device and disable the I2C functionality on the Raspberry Pi.

```
finally {
    if (mpu != null) {
        mpu.close();
    }
}
```

## What's Next?

THANK YOU for participating in this learning experience!

We have reached the end of this Tutorial. If you find errors, omissions, or if you have suggestions and/or questions about the Tutorial or component contents of this Kit, please feel free to contact us:

[support@freenove.com](mailto:support@freenove.com)

We will make every effort to make changes and correct errors as soon as feasibly possible and publish a revised version.

If you want to learn more about Arduino, Raspberry Pi, Smart Cars, Robotics and other interesting products in science and technology, please continue to visit our website. We will continue to launch fun, cost-effective, innovative and exciting products.

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