Lab Manual for IECE 553/453
Cyber-Physical Systems
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Chapter 1

Setup Headless Raspberry Pi

This tutorial is to setup the Raspberry Pi without requirement of any keyboard, mouse or monitor. You should be able to `ssh` into the Pi from your laptop using an Ethernet cable.

1.1 Boot up Raspberry Pi for the first time

1. Download Raspbian (Desktop version) from the official Raspberry Pi website (`https://www.raspberrypi.org/downloads/raspbian/`).
2. Use the tool Etcher (`https://etcher.io`) to burn the Raspbian in the Micro SD card.
3. Create an empty file in `boot` partition of the Micro SD card and name it `ssh` without any extension. Use commands `touch` in Linux/OSX or `fsutil` in Windows. This enables `ssh` in Raspberry Pi.
4. Insert the Micro SD card in the Raspberry Pi and power it. This will boot up in Raspbian with SSH being enabled.

1.2 Login to your Raspberry Pi and setup hostname

1. Connect Raspberry Pi to your Home Router using Ethernet cable.
2. From your laptop (also connected to your Home Router by wired or wireless connection), use ssh to connect to the Raspberry Pi. The default values are:
   ```
   hostname: raspberrypi
   username: pi
   password: raspberry
   ```
   If you are using Linux or OSX, you can use the following command to ssh in with X-forwarding enabled: `ssh -X pi@raspberrypi.local`
   If you are using Windows, choose PuTTY to ssh in with the same credentials.
3. Expand the Filesystem. Use the following command: `sudo raspi-config`. Choose Option 6, Advanced Options, then choose A1 Expand Filesystem. Save the changes
4. Change the hostname. Use `sudo raspi-config`. Choose Option 1, System Options. Then choose S4 Hostname. Enter the hostname of your choice, for example mine is `sahaPi`. Reboot for the changes to be affected.

1.3 Create new User

1. Add new user. In terminal, use the following command. `sudo adduser newusername`, for example I used `sudo adduser dsaha` You will be asked to provide password.
2. Add user to sudo group using the following command: `sudo usermod -aG sudo dsaha`. Check if the command worked without any error. The output of the following command will show both `pi` and `newusername` as the sudo users. `cat /etc/group | grep sudo`
3. Reboot as new user, ‘`dsaha`’ in my case.

4. Use the following two commands to disconnect user `pi` from all default services.
   a) Open the file `/etc/lightdm/lightdm.conf`. `sudo nano /etc/lightdm/lightdm.conf`
   Change the line: `autologin-user=pi` to `autologin-user=dsaha`
   b) In command line, use the command: `sudo systemctl stop autologin@tty1`

5. Delete the user `pi`.
   Use the command: `sudo userdel pi`.
   If you are NOT able to delete the user `pi`, perform the following steps:

   - Use the command, `sudo raspi-config`.
   - Choose: option 1 System Options → S5 Boot → Console AutoLogin: Text console, automatically logged in as 'new user'. Save changes.
   - You will be prompted to reboot. If not reboot manually using `sudo reboot`.
   - Remotely connect to the raspberry pi again as in Step 1.2.2.
   - Remove the default user `pi` using the command: `sudo userdel pi`

6. Shutdown the Pi using the command `sudo shutdown -h now`

1.4 Connect directly to your laptop

1. Now connect the Raspberry Pi directly to your laptop using Ethernet cable. We will use Laptop's Wi-Fi connection to access the Internet and Ethernet to communicate to the Raspberry Pi.

2. Share the Internet Connection in your Laptop. Use the appropriate link for your Operating System and version to enable this.

   Windows: https://answers.microsoft.com/en-us/windows/forum/windows_10-networking/internet-connection-sharing-in-windows-10/f6dcac4b-5203-4c98-8cf2-dcac86d98fb9
   Ubuntu : https://help.ubuntu.com/community/Internet/ConnectionSharing
   MAC : https://support.apple.com/kb/ph25327?locale=en_US

3. SSH directly to the Pi. Use `ssh -X username@hostname.local`. In my case, it is `ssh -X dsaha@sahaPi.local`.

1.5 Initial setup

1. Make sure that the Raspberry Pi is up to date with the latest versions of Raspbian: (this is a good idea to do regularly, anyway).

   ```
   sudo apt-get update
   ```

   ```
   sudo apt-get upgrade
   ```

2. Setting up RPi libraries,
   The RPi.GPIO module is installed by default in Raspbian Desktop image. To make sure that it is at the latest version:
   ```
   sudo apt-get install python-rpi.gpio python3-rpi.gpio
   ```

3. Setting up GPIO Zero libraries,
   GPIO Zero is installed by default in the Raspbian image, and the Raspberry Pi Desktop image. However it can be installed or updated using,
   `sudo apt install python3-gpiozero` (for Python 3)
   `sudo apt install python-gpiozero` (for Python 2)

4. Setting up Exploring Raspberry pi libraries,
   ```
   sudo apt-get install git
   git clone https://github.com/derekmolloy/exploringrpi.git
   ```

5. WiringPi is pre-installed with standard Raspbian systems. However it can be installed or updated using,

```
    sudo apt-get install wiringpi
```

1.6 Shutdown and Restart

After every use, make sure to properly shutdown the Pi using the command:
`sudo shutdown -h now`.
To reboot the Pi, use the following command:
`sudo reboot`

Chapter 2

The First Circuit

We will use GPIO to Breadboard Interface Board with GPIO Ribbon Cable to connect the Raspberry PI for ease of use. Figure 2.1 shows the connection. Make sure the red line of the breadboard is aligned with positive voltage in the interface board, as shown in Figure 2.2.

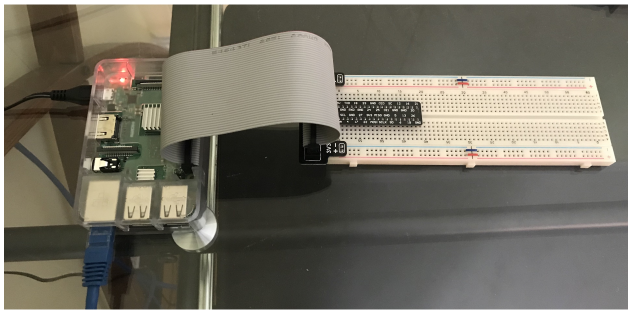
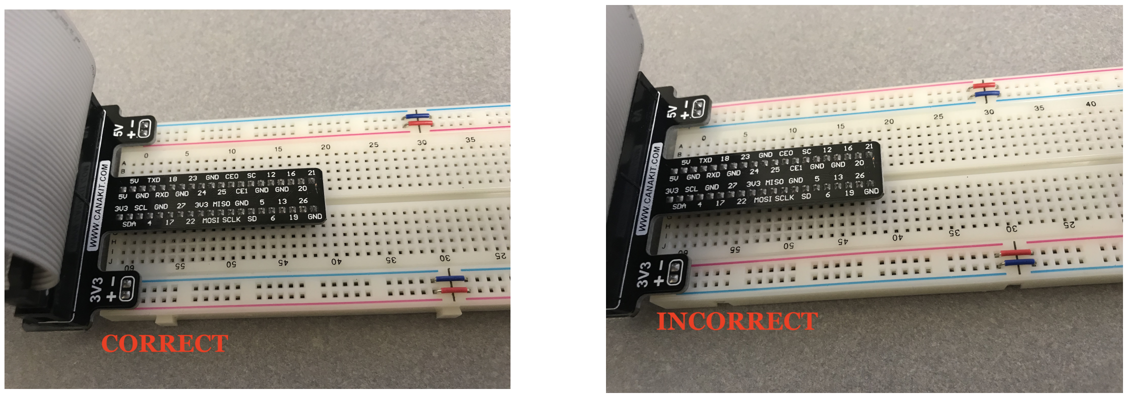


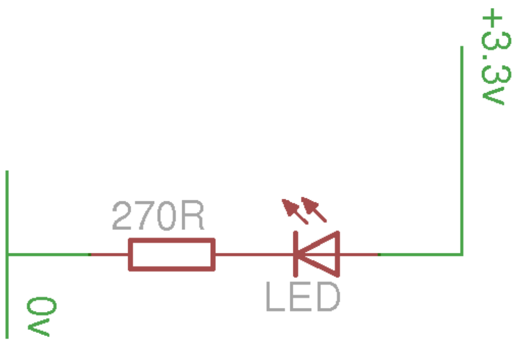
Figure 2.1: GPIO to Breadboard Interface Board and Ribbon Cable.



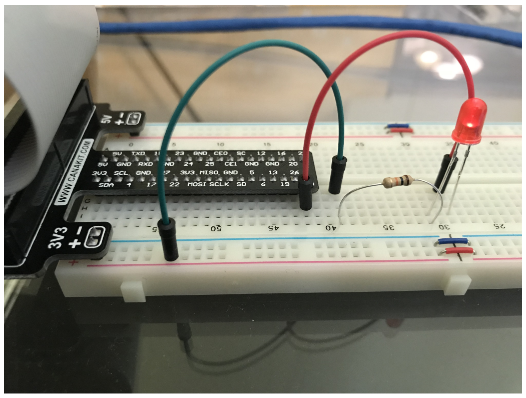
(a) Red line matching positive.

(b) Red line not matching positive.

Figure 2.2: Breadboard.



(a) Schematic Diagram.



(b) Circuit on breadboard.

Figure 2.3: LED Resistor Circuit.

The first circuit that we will work on is shown in Figure 2.3. It is the simplest circuit, where the circuit is always connected to +3.3V line. This will keep the LED turned on until the circuit is disconnected.

Once you complete the circuit and LED is turned on, you have completed the first circuit. Congratulations!

Chapter 3

Basic Input and Output Using Pseudo Filesystem

3.1 Programming The First Circuit Using `sysfs`

We will use the GPIO pins to program the controlling of the LED. Our Raspberry Pi uses Raspbian based on Debian and optimized for the Raspberry Pi hardware. We will use `sysfs` to access the kernel space for controlling the GPIO pins. Change the circuit to get power from GPIO pin 4 instead of 3.3V as shown in figure 3.1.

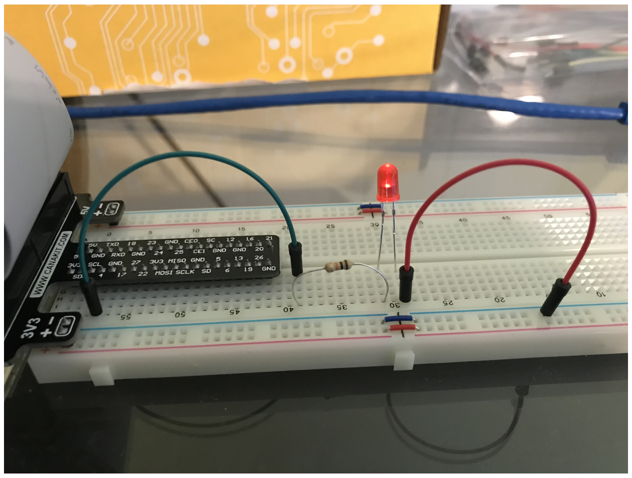


Figure 3.1: LED Resistor Circuit connected to GPIO Pin 4.

The steps for controlling the GPIO pin using `sysfs` is given below.

1. Become the Sudo user to access `sysfs`.

   ```
   dsaha@sahaPi:~ $ sudo su
   ```

2. Go to the GPIO folder and list the contents

   ```
   root@sahaPi:/home/dsaha# cd /sys/class/gpio/
   root@sahaPi:/sys/class/gpio# ls
   export gpiochip0 gpiochip128 unexport
   ```

3. Export gpio 4

   ```
   root@sahaPi:/sys/class/gpio# echo 4 > export
   root@sahaPi:/sys/class/gpio# ls
   export gpio4 gpiochip0 gpiochip504 unexport
   ```

4. Go to the gpio4 folder and list contents

```
root@sahaPi:/sys/class/gpio# cd gpio4/
root@sahaPi:/sys/class/gpio/gpio4# ls
active_low device direction edge power subsystem uevent value
```

5. Set direction (in or out) of pin

```
root@sahaPi:/sys/class/gpio/gpio4# echo out > direction
```

6. Set value to be 1 to turn on the LED

```
root@sahaPi:/sys/class/gpio/gpio4# echo 1 > value
```

7. Set value to be 0 to turn off the LED

```
root@sahaPi:/sys/class/gpio/gpio4# echo 0 > value
```

8. Check the status (direction and value) of the pin

```
root@sahaPi:/sys/class/gpio/gpio4# cat direction
out
root@sahaPi:/sys/class/gpio/gpio4# cat value
0
```

9. Ready to give up the control? Get out of gpio4 folder and list contents, which shows gpio4 folder

```
root@sahaPi:/sys/class/gpio/gpio4# cd ../
root@sahaPi:/sys/class/gpio# ls
export gpio4 gpiochip0 gpiochip128 unexport
```

10. Unexport gpio 4 and list contents showing removal of gpio4 folder

```
root@sahaPi:/sys/class/gpio# echo 4 > unexport
root@sahaPi:/sys/class/gpio# ls
export gpiochip0 gpiochip504 unexport
```

3.2 The First Circuit Using Bash, Python and C

Listing 3.1 [1] shows the bash script to turn on or off the LED using GPIO pins. Note that each step in the script is same as shown in §3.1. Listings 3.2 and 3.3 show similar procedure in Python and C languages respectively.

Listing 3.1: LED code in Bash script

```
#!/bin/bash
#  A small Bash script to turn on and off an LED that is attached to GPIO 4
#  using Linux sysfs. Written by Derek Molloy (www.derekmolloy.ie) for the
#  book Exploring Raspberry PI
LED_GPIO=4   # Use a variable -- easy to change GPIO number

# An example Bash functions
function setLED
{ # $1 is the first argument that is passed to this function
  echo $1 >> "/sys/class/gpio/gpio$LED_GPIO/value"
}

# Start of the program -- start reading from here
if [ $# -ne 1 ]; then   # if there is not exactly one argument
  echo "No␣command␣was␣passed.␣Usage␣is:␣bashLED␣command,"
  echo "where␣command␣is␣one␣of:␣setup,␣on,␣off,␣status␣and␣close"
  echo -e "␣e.g.,␣bashLED␣setup,␣followed␣by␣bashLED␣on"
  exit 2     # error that indicates an invalid number of arguments
fi
echo "The␣LED␣command␣that␣was␣passed␣is:␣$1"
```

[1] This part of the lab follows the book ”Exploring Raspberry Pi: Interfacing to the Real World with Embedded Linux”, by Derek Molloy, Wiley, ISBN 978-1-119-18868-1, 2016.

```
if [ "$1" == "setup" ]; then
  echo "Exporting␣GPIO␣number␣$1"
  echo $LED_GPIO >> "/sys/class/gpio/export"
  sleep 1    # to ensure gpio has been exported before next step
  echo "out" >> "/sys/class/gpio/gpio$LED_GPIO/direction"
elif [ "$1" == "on" ]; then
  echo "Turning␣the␣LED␣on"
  setLED 1    # 1 is received as $1 in the setLED function
elif [ "$1" == "off" ]; then
  echo "Turning␣the␣LED␣off"
  setLED 0    # 0 is received as $1 in the setLED function
elif [ "$1" == "status" ]; then
  state=$(cat "/sys/class/gpio/gpio$LED_GPIO/value")
  echo "The␣LED␣state␣is:␣$state"
elif [ "$1" == "close" ]; then
  echo "Unexporting␣GPIO␣number␣$LED_GPIO"
  echo $LED_GPIO >> "/sys/class/gpio/unexport"
fi
```

Listing 3.2: LED code in Python

```
#!/usr/bin/python2
# A small Python program to set up GPIO4 as an LED that can be
# turned on or off from the Linux console.
# Written by Derek Molloy for the book "Exploring Raspberry Pi"

import sys
from time import sleep
LED4_PATH = "/sys/class/gpio/gpio4/"
SYSFS_DIR = "/sys/class/gpio/"
LED_NUMBER = "4"

def writeLED ( filename, value, path=LED4_PATH ):
   "This␣function␣writes␣the␣value␣passed␣to␣the␣file␣in␣the␣path"
   fo = open( path + filename,"w")
   fo.write(value)
   fo.close()
   return

print "Starting␣the␣GPIO␣LED4␣Python␣script"
if len(sys.argv)!=2:
   print "There␣is␣an␣incorrect␣number␣of␣arguments"
   print "␣␣usage␣is:␣␣pythonLED.py␣command"
   print "␣␣where␣command␣is␣one␣of␣setup,␣on,␣off,␣status,␣or␣close"
   sys.exit(2)
if sys.argv[1]=="on":
   print "Turning␣the␣LED␣on"
   writeLED (filename="value", value="1")
elif sys.argv[1]=="off":
   print "Turning␣the␣LED␣off"
   writeLED (filename="value", value="0")
elif sys.argv[1]=="setup":
   print "Setting␣up␣the␣LED␣GPIO"
   writeLED (filename="export", value=LED_NUMBER, path=SYSFS_DIR)
   sleep(0.1);
   writeLED (filename="direction", value="out")
elif sys.argv[1]=="close":
   print "Closing␣down␣the␣LED␣GPIO"
   writeLED (filename="unexport", value=LED_NUMBER, path=SYSFS_DIR)
```

```
elif sys.argv[1]=="status":
   print "Getting␣the␣LED␣state␣value"
   fo = open( LED4_PATH + "value", "r")
   print fo.read()
   fo.close()
else:
   print "Invalid␣Command!"
print "End␣of␣Python␣script"
```

Listing 3.3: LED code in C

```
/** Simple On-board LED flashing program - written in C by Derek Molloy
*    simple functional struture for the Exploring Raspberry Pi book
*
*    This program uses GPIO4 with a connected LED and can be executed:
*          makeLED setup
*          makeLED on
*          makeLED off
*          makeLED status
*          makeLED close
*/

#include<stdio.h>
#include<stdlib.h>
#include<string.h>

#define GPIO_NUMBER "4"
#define GPIO4_PATH "/sys/class/gpio/gpio4/"
#define GPIO_SYSFS "/sys/class/gpio/"

void writeGPIO(char filename[], char value[]){
   FILE* fp;                           // create a file pointer fp
   fp = fopen(filename, "w+");         // open file for writing
   fprintf(fp, "%s", value);           // send the value to the file
   fclose(fp);                         // close the file using fp
}

int main(int argc, char* argv[]){
   if(argc!=2){                        // program name is argument 1
      printf("Usage␣is␣makeLEDC␣and␣one␣of:\n");
      printf("␣␣␣setup,␣on,␣off,␣status,␣or␣close\n");
      printf("␣e.g.␣makeLEDC␣on\n");
      return 2;                        // invalid number of arguments
   }
   printf("Starting␣the␣makeLED␣program\n");
   if(strcmp(argv[1],"setup")==0){
      printf("Setting␣up␣the␣LED␣on␣the␣GPIO\n");
      writeGPIO(GPIO_SYSFS "export", GPIO_NUMBER);
      usleep(100000);                  // sleep for 100ms
      writeGPIO(GPIO4_PATH "direction", "out");
   }
   else if(strcmp(argv[1],"close")==0){
      printf("Closing␣the␣LED␣on␣the␣GPIO\n");
      writeGPIO(GPIO_SYSFS "unexport", GPIO_NUMBER);
   }
   else if(strcmp(argv[1],"on")==0){
      printf("Turning␣the␣LED␣on\n");
      writeGPIO(GPIO4_PATH "value", "1");
   }
   else if (strcmp(argv[1],"off")==0){
      printf("Turning␣the␣LED␣off\n");
      writeGPIO(GPIO4_PATH "value", "0");
   }
   else if (strcmp(argv[1],"status")==0){
      FILE* fp;        // see writeGPIO function above for description
      char line[80], fullFilename[100];
      sprintf(fullFilename, GPIO4_PATH "/value");
      fp = fopen(fullFilename, "rt");        // reading text this time
      while (fgets(line, 80, fp) != NULL){
         printf("The␣state␣of␣the␣LED␣is␣%s", line);
      }
      fclose(fp);
   }
   else{
      printf("Invalid␣command!\n");
   }
   printf("Finished␣the␣makeLED␣Program\n");
   return 0;
}
```

3.3 Simple Circuit Using Python Libraries

3.3.1 RPi Library

In this section, we will use `RPi` Python library to demonstrate similar LED switching functions. Listing 3.4 shows a simple code in Python for GPIO pin manipulation. Check the website [https://sourceforge.net/projects/raspberry-gpio-python/] to learn other functions available through this library. Note that the current release does not support SPI, I2C, 1-wire or serial functionality on the RPi yet.

Listing 3.4: LED code using RPi Library in Python

```
import RPi.GPIO as GPIO
from time import sleep

ledPin = 4                      # GPIO Pin Number, where LED is connected

GPIO.setmode(GPIO.BCM)          # Broadcom pin-numbering scheme
GPIO.setup(ledPin, GPIO.OUT)    # LED pin set as output

GPIO.output(ledPin, GPIO.HIGH)  # Turn the LED on
sleep(1)                        # Sleep for 1 sec
GPIO.output(ledPin, GPIO.LOW)   # Turn the LED off
GPIO.cleanup()                  # Clean up at the end of the program
```

3.3.2 GPIOZero Library

Another efficient Python library is `gpiozero` [https://gpiozero.readthedocs.io/en/stable/]. It provides a simple interface to GPIO devices with Raspberry Pi. It was created by Ben Nuttall of the Raspberry Pi Foundation, Dave Jones, and other contributors. Listing 3.5 shows a simple code for switching on and off the LED.

Listing 3.5: LED code using GPIOZero Library in Python

```
from gpiozero import LED
from time import sleep

led = LED(4)     # GPIO Pin Number
led.on()         # Turn on LED
sleep(1)         # Sleep for 1 sec
led.off()        # Turn off LED
```

3.4 Use GPIO Pins for Input

In the next experiment, we will use GPIO Pin as an input. The circuit is shown as in figure 3.2. A button switch, when pressed, will be detected by the program and a message will be printed accordingly. In this case, the process continuously polls the status of the input pin. Listings 3.6 and 3.7 shows the code using `RPi` and `gpiozero` libraries.

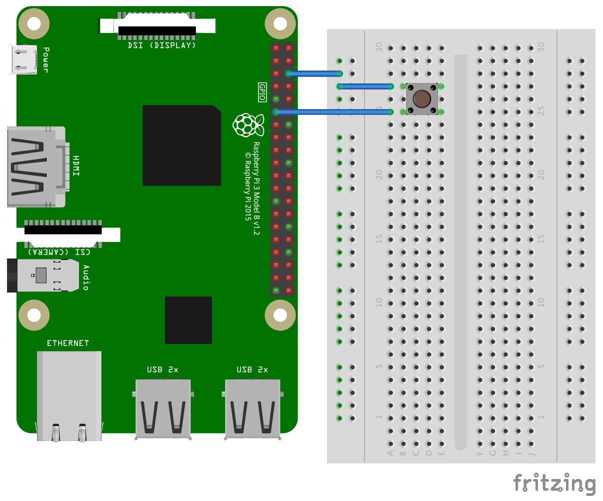


Figure 3.2: Button Switch connected to GPIO Pin.

Listing 3.6: Button Press detection code using RPi Library in Python

```python
import RPi.GPIO as GPIO
import time

buttonPin=17     # GPIO Pin Number where Button Switch is connected

GPIO.setmode(GPIO.BCM)            # Broadcom pin-numbering scheme
GPIO.setup(buttonPin, GPIO.IN, pull_up_down=GPIO.PUD_UP)
# Button pin set as input

while True:                             # Monitor continuously
    input_state = GPIO.input(buttonPin) # Get the input state
    if input_state == False:            # Check status
        print('Button␣Pressed')         # Print
        time.sleep(0.2)                 # Sleep before checking again
```

Listing 3.7: Button Press detection code using GPIOZero Library in Python

```python
from gpiozero import Button
import time

button = Button(17) # GPIO Pin Number where Button Switch is connected

while True:                             # Monitor continuously
    if button.is_pressed:               # Check Status
        print("Button␣Pressed")         # Print
        time.sleep(0.2)                 # Sleep before checking again
```

Chapter 4

Analog Output: PWM (Pulse Width Modulation)

The RPi has pulse-width modulation (PWM) capabilities that can provide digital-to-analog conversion (DAC), or generate control signals for motors and certain types of servos. The number of PWM outputs is very limited on the RPi boards. The RPi B+ model has two PWMs (PWM0 & PWM1) output at Pins 12 and 33 (GPIO18, GPIO13).

$$PWM\ frequency = \frac{19.2MHz}{(divisor \times range)} \tag{4.1}$$

The PWM device on the RPi is clocked at a fixed base-clock frequency of 19.2 MHz, and therefore integer divisor and range values are used to tailor the PWM frequency for your application according to the following expression: where the range is subsequently used to adjust the duty cycle of the PWM signal. RPi PWMs share the same frequency but have independent duty cycles. The default PWM mode of operation on the RPi is to use balanced PWM. Balanced PWM means that the frequency will change as the duty cycle is adjusted, therefore to control the frequency you need to use the call `pwmSetMode(PWM_MODE_MS)` to change the mode to mark-space.

4.1 Circuit

Create a circuit similar to the one shown in Figure 3.1.

4.2 Hard PWM

Listing 4.1 shows a PWM example, which uses both PWMs on the RPi to generate two signals with different duty cycles. The script can be accessed by navigating to
`exploringPi/chp06/wiringPi/pwm.cpp` Implement the circuit corresponding to the script to turn on two LEDs using an Analog output. LEDs are current-controlled devices, so PWM is typically employed to provide brightness-level control. This is achieved by flashing the LED faster than can be perceived by a human, where the amount of time that the LED remains on, versus off (i.e., the duty cycle) affects the human-perceived brightness level. **Note:** To compile this code use: `g++ pwm.cpp -o pwm -lwiringPi`.

Listing 4.1: PWM code in C++

```cpp
#include <iostream>
#include <wiringPi.h>
using namespace std;

#define PWM0       12                    // this is physical pin 12
#define PWM1       33                    // only on the RPi B+/A+/2

int main() {                             // must be run as root
   wiringPiSetupPhys();                  // use the physical pin numbers
   pinMode(PWM0, PWM_OUTPUT);            // use the RPi PWM output
   pinMode(PWM1, PWM_OUTPUT);            // only on recent RPis

   // Setting PWM frequency to be 10kHz with a full range of 128 steps
   // PWM frequency = 19.2 MHz / (divisor * range)
   // 10000 = 19200000 / (divisor * 128) => divisor = 15.0 = 15
   pwmSetMode(PWM_MODE_MS);                // use a fixed frequency
   pwmSetRange(128);                       // range is 0-128
   pwmSetClock(15);                        // gives a precise 10kHz signal
   cout << "The PWM Output is enabled" << endl;
   pwmWrite(PWM0, 32);                     // duty cycle of 25% (32/128)
   pwmWrite(PWM1, 64);                     // duty cycle of 50% (64/128)
   return 0;                               // PWM output stays on after exit
}
```

4.2.1 PWM Application: Fading an LED

Listing 4.2 provides a code example for slowly fading an LED on and off using PWM. Implement the circuit corresponding to the script to fade in and out and LED.

Listing 4.2: PWM code in C++

```
#include <iostream>
#include <wiringPi.h>
#include <unistd.h>
using namespace std;
#define PWM_LED       18           // this is PWM0, Pin 12
bool running = true;               // fade in/out until button pressed
int main() {                             // must be run as root
   wiringPiSetupGpio();                  // use the GPIO numbering
   pinMode(PWM_LED, PWM_OUTPUT);         // the PWM LED - PWM0
   cout << "Fading the LED in/out" << endl;
   for(int i=1; i<=1023; i++) {        // Fade fully on
         pwmWrite(PWM_LED, i);
         usleep(2000);
   }
   for(int i=1022; i>=0; i--) {        // Fade fully off
         pwmWrite(PWM_LED, i);
         usleep(2000);
   }

   pwmWrite(PWM_LED, 1023);
   cout << "LED Off: Program has finished gracefully!" << endl;
   return 0;
}
```

4.3 Soft PWM

It is possible to use software PWM on the other GPIO pins by toggling the GPIO, but this approach has a high CPU cost and is only suitable for low-frequency PWM signals. Alternatively, additional circuity can be used to add hardware PWMs to each I^{2}C bus. WiringPi includes a software-driven PWM handler capable of outputting a PWM signal on any of the Raspberry Pi's GPIO pins. An example of Software PWM is shown in Listing 4.3. Implement the circuit corresponding to the above script to turn on two LEDs using a Sofware PWM output.

Listing 4.3: PWM code in C

```
#include <wiringPi.h>
#include <softPwm.h>
#include <unistd.h>

#define GPIO1 4
#define GPIO2 17

int main(int argc, char *argv[])
{
   if (wiringPiSetupGpio() < 0) return 1;
```

```
    pinMode(GPIO1, OUTPUT);
    digitalWrite(GPIO1, LOW);
    //int softPwmCreate (int pin, int initialValue, int pwmRange) ;
    softPwmCreate(GPIO1, 0, 200);
    // void softPwmWrite (int pin, int value) ;
    softPwmWrite(GPIO1, 15);

    pinMode(GPIO2, OUTPUT);
    digitalWrite(GPIO2, LOW);
    softPwmCreate(GPIO2, 0, 500);
    softPwmWrite(GPIO2, 15);
    sleep(10);
}
```

This can also be done using the gpiozero using the following scripts.

Listing 4.4: LED code in Python

```python
from gpiozero import PWMLED
from time import sleep

led = PWMLED(17)

while True:
    led.value = 0  # off
    sleep(1)
    led.value = 0.5  # half brightness
    sleep(1)
    led.value = 1  # full brightness
    sleep(1)
```

Listing 4.5: LED code in Python

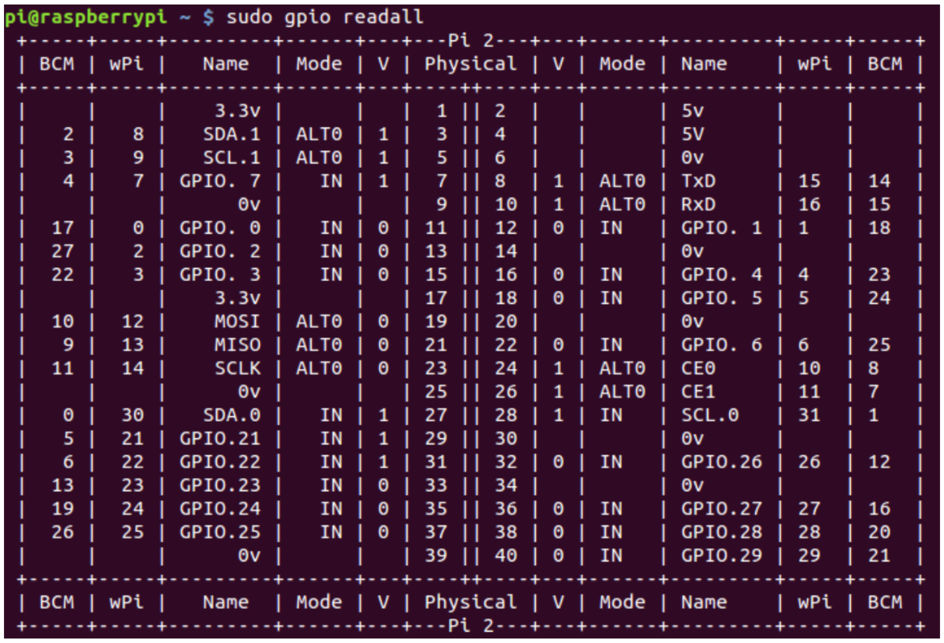
```python
from gpiozero import PWMLED
from signal import pause

led = PWMLED(17)

led.pulse()

pause()
```

Chapter 5

Analog Input

In this lab we will work learn how to use the Raspberry pi for Analog input.

The default configurations of the RPi GPIO pins can be viewed by querying the following in termianl:
`sudo gpio readall`
This will display the default configurations as shown in Figure 5.1. Make sure to use the correct pin as initialized in the initial setup of wiringPi (`http://wiringpi.com/reference/setup/`).



```
pi@raspberrypi ~ $ sudo gpio readall
 +-----+-----+---------+------+---+---Pi 2---+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 |     |     |    3.3v |      |   |  1 || 2  |   |      | 5v      |     |     |
 |   2 |   8 |   SDA.1 | ALT0 | 1 |  3 || 4  |   |      | 5V      |     |     |
 |   3 |   9 |   SCL.1 | ALT0 | 1 |  5 || 6  |   |      | 0v      |     |     |
 |   4 |   7 | GPIO. 7 |   IN | 1 |  7 || 8  | 1 | ALT0 | TxD     | 15  | 14  |
 |     |     |      0v |      |   |  9 || 10 | 1 | ALT0 | RxD     | 16  | 15  |
 |  17 |   0 | GPIO. 0 |   IN | 0 | 11 || 12 | 0 | IN   | GPIO. 1 | 1   | 18  |
 |  27 |   2 | GPIO. 2 |   IN | 0 | 13 || 14 |   |      | 0v      |     |     |
 |  22 |   3 | GPIO. 3 |   IN | 0 | 15 || 16 | 0 | IN   | GPIO. 4 | 4   | 23  |
 |     |     |    3.3v |      |   | 17 || 18 | 0 | IN   | GPIO. 5 | 5   | 24  |
 |  10 |  12 |    MOSI | ALT0 | 0 | 19 || 20 |   |      | 0v      |     |     |
 |   9 |  13 |    MISO | ALT0 | 0 | 21 || 22 | 0 | IN   | GPIO. 6 | 6   | 25  |
 |  11 |  14 |    SCLK | ALT0 | 0 | 23 || 24 | 1 | ALT0 | CE0     | 10  | 8   |
 |     |     |      0v |      |   | 25 || 26 | 1 | ALT0 | CE1     | 11  | 7   |
 |   0 |  30 |   SDA.0 |   IN | 1 | 27 || 28 | 1 | IN   | SCL.0   | 31  | 1   |
 |   5 |  21 | GPIO.21 |   IN | 1 | 29 || 30 |   |      | 0v      |     |     |
 |   6 |  22 | GPIO.22 |   IN | 1 | 31 || 32 | 0 | IN   | GPIO.26 | 26  | 12  |
 |  13 |  23 | GPIO.23 |   IN | 0 | 33 || 34 |   |      | 0v      |     |     |
 |  19 |  24 | GPIO.24 |   IN | 0 | 35 || 36 | 0 | IN   | GPIO.27 | 27  | 16  |
 |  26 |  25 | GPIO.25 |   IN | 0 | 37 || 38 | 0 | IN   | GPIO.28 | 28  | 20  |
 |     |     |      0v |      |   | 39 || 40 | 0 | IN   | GPIO.29 | 29  | 21  |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+---Pi 2---+---+------+---------+-----+-----+
```

Figure 5.1: Default GPIO configurations.

5.1 Temperature & Humidity Sensor

Sensor: In this section we will learn how to use DHT-11 to read temperature and humidity data and display it on the terminal. DHT-11 features a temperature and humidity sensor module with a calibrated digital signal output. This sensor includes a resistive humidity measurement component and an NTC (Negative Temperature Coefficient) temperature measurement component, and connects to an 8-bit microcontroller to communicate with the RPi. Complete the circuit as shown in Figure 5.2.

Communicating to One-Wire Sensors: DHT11 can digitally communicate with the RPi using a single GPIO. The GPIO can be set high and low with respect to time to send data bits to the sensor to initiate communication. The same

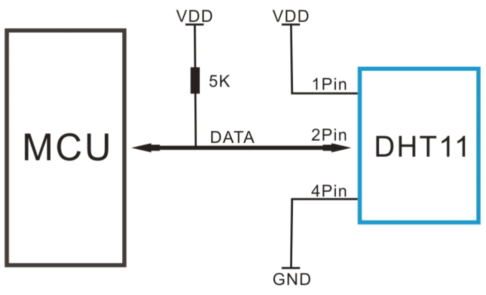


Figure 5.2: Temperature & Humidity Sensor circuit.

GPIO can then be sampled over time to read the sensor's response. Communication takes place when the RPi pulls the GPIO low for $18ms$ and then releases the line high for a further 20–$40\mu s$. The GPIO switches to read mode and ignores the $80\mu s$ low level and the $80\mu s$ high pulse that follows. The sensor then returns 5 bytes of data (i.e., 40-bits) in most-significant bit (MSB) first form, where the first 2 bytes represent the humidity value, the following 2 bytes represent the temperature, and the final byte is a parity-sum, which can be used to verify that the received data is valid (it is the 8-bit bounded sum of the preceding 4 bytes). The bits are sent by varying the duration of high pulses. When DHT is sending data to MCU, every bit of data begins with the $50\mu s$ low-voltage-level and the length of the following high-voltage-level signal determines whether data bit is "0" or "1" A high for $26\mu s$–$28\mu s$ signifies a binary 0, and a high for $70\mu s$ signifies a binary 1. Figure 5.3 illustrates an actual oscilloscope data capture and worked calculations to explain the process for the DHT11.

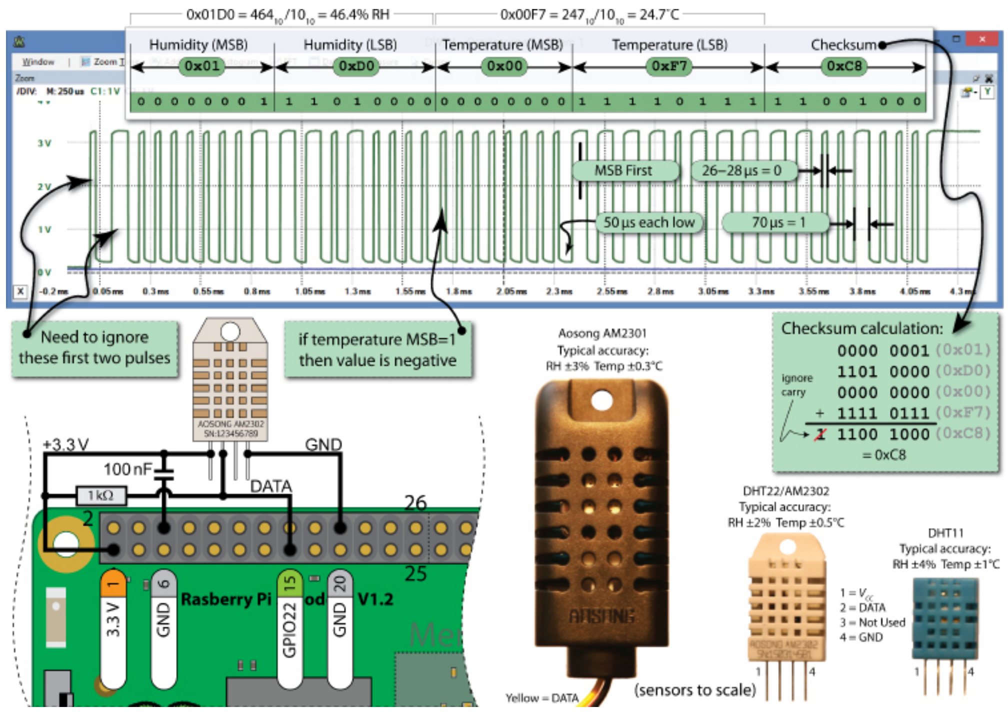


Figure 5.3: Data captured from DHT11.

The script to read the temperature and humidity is available at `/exploringrpi/chp06/dht/dht.cpp`. The code is modified for correct implementation.

Listing 5.1: DHT code in C++

```cpp
#include<iostream>
#include<unistd.h>
#include<wiringPi.h>
#include<iomanip>

using namespace std;
#define USING_DHT11 true // The DHT11 uses only 8 bits
#define DHT_GPIO 22 // Using GPIO 22 for this example
#define LH_THRESHOLD 26 // Low= 1 4 , High= 3 8 - pick avg.

int main(){
    double humid = 0, temp = 0;
    cout << "Starting␣the␣one-wire␣sensor␣program" << endl;
    wiringPiSetupGpio();
    piHiPri(99);
TRYAGAIN: // If checksum fails (come back here)
    unsigned char data[5] = {0,0,0,0,0};
    pinMode(DHT_GPIO, OUTPUT); // gpio starts as output
    digitalWrite(DHT_GPIO, LOW); // pull the line low
    usleep(18000); // wait for 18ms
    digitalWrite(DHT_GPIO, HIGH); // set the line high
    pinMode(DHT_GPIO, INPUT); // now gpio is an input

    // need to ignore the first and second high after going low
    do { delayMicroseconds(1); } while(digitalRead(DHT_GPIO)==HIGH);
    do { delayMicroseconds(1); } while(digitalRead(DHT_GPIO)==LOW);
    do { delayMicroseconds(1); } while(digitalRead(DHT_GPIO)==HIGH);
    // Remember the highs, ignore the lows -- a good philosophy!
    for(int d=0; d<5; d++) { // for each data byte
        // read 8 bits
        for(int i=0; i<8; i++) { // for each bit of data
            do { delayMicroseconds(1); } while(digitalRead(DHT_GPIO)==LOW);
            int width = 0; // measure width of each high
            do {
                width++;
                delayMicroseconds(1);
                if(width>1000) break; // missed a pulse -- data invalid!
            } while(digitalRead(DHT_GPIO)==HIGH); // time it!
            // shift in the data, msb first if width > the threshold
            data[d] = data[d] | ((width > LH_THRESHOLD) << (7-i));
        }
    }
    if (USING_DHT11){
        humid = data[0]; // one byte - no fraction_tempal part
        temp = data[2] ;

        if(data[3] < 10.0){
            double fraction_temp = double(data[3])/10.0;
            temp = temp+ fraction_temp;
        }
        else if(data[3] < 100.0){
            double fraction_temp = double(data[3])/100.0;
            temp = temp+ fraction_temp;
        }
        else {
            double fraction_temp = double(data[3])/1000.0;
            temp = temp+ fraction_temp;
        }

        if(data[1] < 10.0){
            double fraction_humid = double(data[1])/10.0;
            humid = humid+ fraction_humid;
        }
        else if(data[1] < 100.0){
            double fraction_humid = double(data[1])/100.0;
            humid = humid+ fraction_humid;
        }
        else {
            double fraction_humid = double(data[1])/1000.0;
            humid = humid+ fraction_humid;
        }
    }
    else { // for DHT22 (AM2302/AM2301)
        humid = (data[0]<<8 | data[1]); // shift MSBs 8 bits left and OR LSBs
        temp = (data[2]<<8 | data[3]); // same again for temperature
    }

    unsigned char chk = 0; // the checksum will overflow automatically
    for(int i=0; i<4; i++){ chk+= data[i]; }
    if(chk==data[4]){
        cout << "The␣checksum␣is␣good" << endl;
        cout << "The␣temperature␣is␣" << (float)temp << "C" << endl;
        cout << "The␣humidity␣is␣" << (float)humid << "%" << endl;
    }
    else {
        cout << "Checksum␣bad␣-␣data␣error␣-␣trying␣again!" << endl;
        usleep(2000000); // have to delay for 1-2 seconds between readings
        goto TRYAGAIN; // a GOTO!!! call yourself a C/C++ programmer!
    }
    return 0;
}
```

Chapter 6

Stepper Motor

In this lab, we will learn the principles of Stepper Motor and how to control it with Raspberry Pi. We will use the code that came with your Sensor kit. For that, you can use the following command in your terminal to get all the code.

```
$git clone
https://github.com/adeept/Adeept_Ultimate_Starter_Kit_C_Code_for_RPi.git
```

Stepper Motor: A stepper motor is a motor that converts electrical pulse signals into corresponding angular or linear displacements. Unlike DC motors, which rotate continuously when a DC voltage is applied, stepper motors normally rotate in discrete fixed-angle steps. Each time a pulse signal is input, the rotor rotates by an angle or a step forward. The output angular displacement or linear displacement is proportional to the number of pulses input, and the rotation speed is proportional to the pulse frequency. Therefore, stepper motors are also called pulse motors. Stepper motors can be positioned very accurately, because they typically have a positioning error of less than 5% of a step (i.e., typically 0.1^o). The error does not accumulate over multiple steps, so stepper motors can be controlled in an *open-loop form*, without the need for feedback. The motor from your Sensor kit is shown in Figure 6.1.

ULN2003 Driver Module: The Raspberry Pis GPIO cannot directly drive a stepper motor due to the weak current. Therefore, a driver circuit is necessary to control the stepper motor. This experiment uses the ULN2003 driver module. There are four LEDs on the module to indicate stepping state. The white socket in the middle is for connecting a stepper motor. IN1, IN2, IN3, IN4 are used to connect with the microcontroller. The power supply [5V to 12V DC] and an On/Off jumper also resides on the board as shown in Figure 6.1.

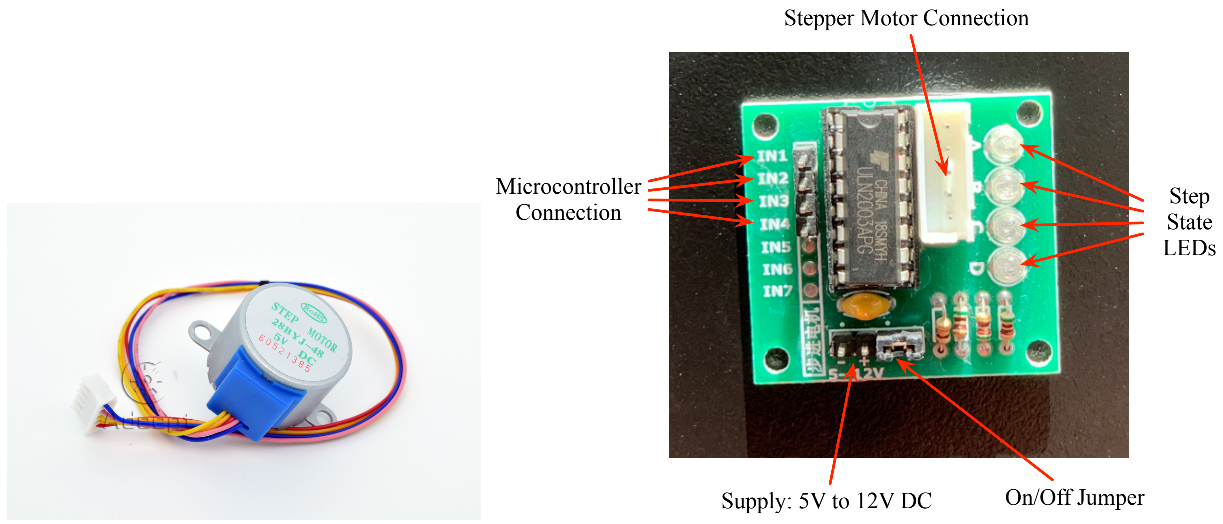


Figure 6.1: Stepper Motor and ULN 2003A.

Circuit: Figure 6.2 shows the circuit connection for the stepper motor with the driver and the Microcontroller. The script to control the Stepper Motor can be accessed at: `Adeept_Ultimate_Starter_Kit_C_Code_for_RPi/24_stepperMotor/stepperMotor.c`. It is also shown in Listing 6.1. Based on the code that you will be using, connect 4 GPIO pins from your Raspberry Pi to the four inputs of the ULN2003A. When connecting the circuit, we should pay attention to the difference between positive and negative poles.

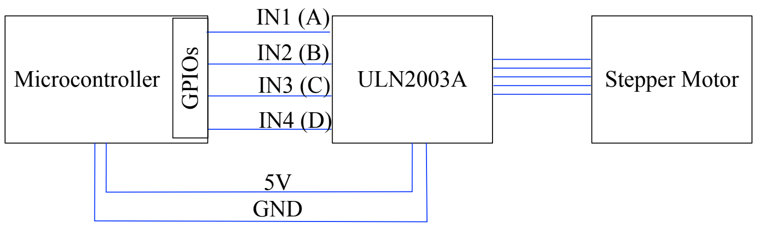


Figure 6.2: Stepper Motor Circuit.

Understanding the Code:

1. The GPIO pins should be output.
2. The four pins should be set at high level for the four pins in sequence to control the clockwise rotation of the stepping motor.
3. The four pins should be set at high level for the four pins in sequence *in reverse order* to control the *anti-clockwise* rotation of the stepping motor.
4. When all output are 0, the driver stops.
5. 512 steps are needed to turn 360°.

Listing 6.1: Stepper Motor Code

```
/*
 * File name   : stepperMotor.c
 * Description : control a stepper motor.
 * Website     : www.adeept.com
 * E-mail      : support@adeept.com
 * Author      : Jason
 * Date        : 2015/06/21
 */
#include <wiringPi.h>
#include <stdio.h>

#define IN1 0    // wiringPi GPIO0(pin11)
#define IN2 1    // pin12
#define IN3 2    // pin13
#define IN4 3    // pin15

void setStep(int a, int b, int c, int d)
{
        digitalWrite(IN1, a);
        digitalWrite(IN2, b);
        digitalWrite(IN3, c);
        digitalWrite(IN4, d);
}

void stop(void)
{
        setStep(0, 0, 0, 0);
}
```

```
void forward(int t, int steps)
{
        int i;

        for(i = 0; i < steps; i++){
                setStep(1, 0, 0, 0);
                delay(t);
                setStep(0, 1, 0, 0);
                delay(t);
                setStep(0, 0, 1, 0);
                delay(t);
                setStep(0, 0, 0, 1);
                delay(t);
        }
}

void backward(int t, int steps)
{
        int i;

        for(i = 0; i < steps; i++){
                setStep(0, 0, 0, 1);
                delay(t);
                setStep(0, 0, 1, 0);
                delay(t);
                setStep(0, 1, 0, 0);
                delay(t);
                setStep(1, 0, 0, 0);
                delay(t);
        }
}

int main(void)
{
        if (wiringPiSetup() < 0) {
                printf("Setup␣wiringPi␣failed!\n");
                return -1;
        }

        /* set pins mode as output */
        pinMode(IN1, OUTPUT);
        pinMode(IN2, OUTPUT);
        pinMode(IN3, OUTPUT);
        pinMode(IN4, OUTPUT);

        while (1){
                printf("forward...\n");
                forward(3, 512);

                printf("stop...\n");
                stop();
                delay(2000);        // 2s

                printf("backward...\n");
                backward(3, 256);  // 512 steps ---- 360 angle

                printf("stop...\n");
                stop();
                delay(2000);       // 2s
        }

        return 0;
}
```

Chapter 7

More Input and Output

In this lab, we will work on another input and output device.

7.1 7 Segment Display

The seven-segment display is a form of electronic display device for displaying decimal numerals that is an alternative to the more complex dot matrix displays. It is an 8-shaped LED display device composed of eight LEDs (including a decimal point). These segments are termed a, b, c, d, e, f, g, dp respectively as shown in 7.1. It can be either common anode or common cathode segment display through internal connections, as you have experienced with RGB LED. When using a common anode LED, the common anode should to be connected to the power supply (VCC); when using a common cathode LED, the common cathode should be connected to the ground (GND). Each segment of a segment display is composed of LED, so a resistor is needed for protecting the LED. A 7-segment display has seven segments for displaying a figure and a segment for displaying a decimal point. If you want to display a number 1, you should only light the segment b and c.

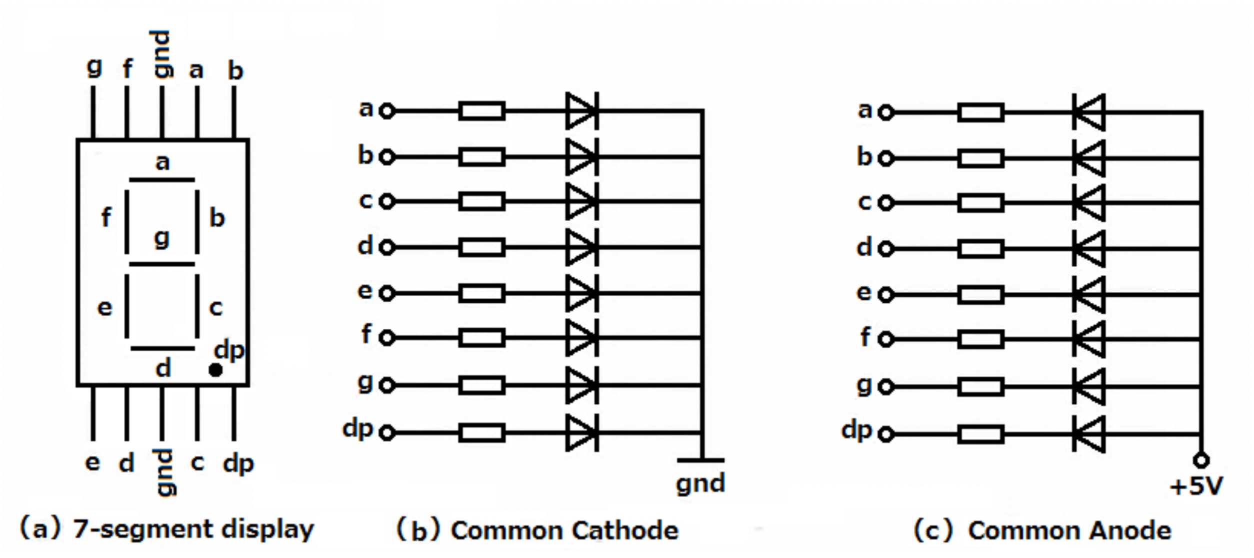


Figure 7.1: 7 segment display.

Figure 7.2 shows the circuit diagram for a common cathode 7 segment display. We will use the code at `Adeept_Ultimate_Starter_Kit_C_Code_for_RPi/09_segment/segment.c` to determine the wiring. The code is shown in Listing 7.1.

Listing 7.1: C code for 7 Segment Display

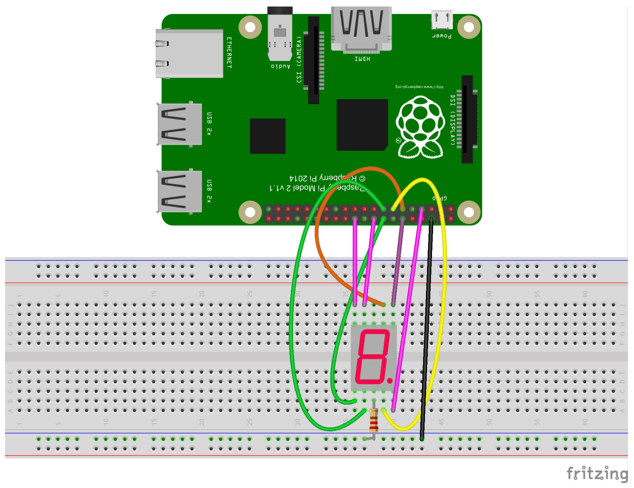
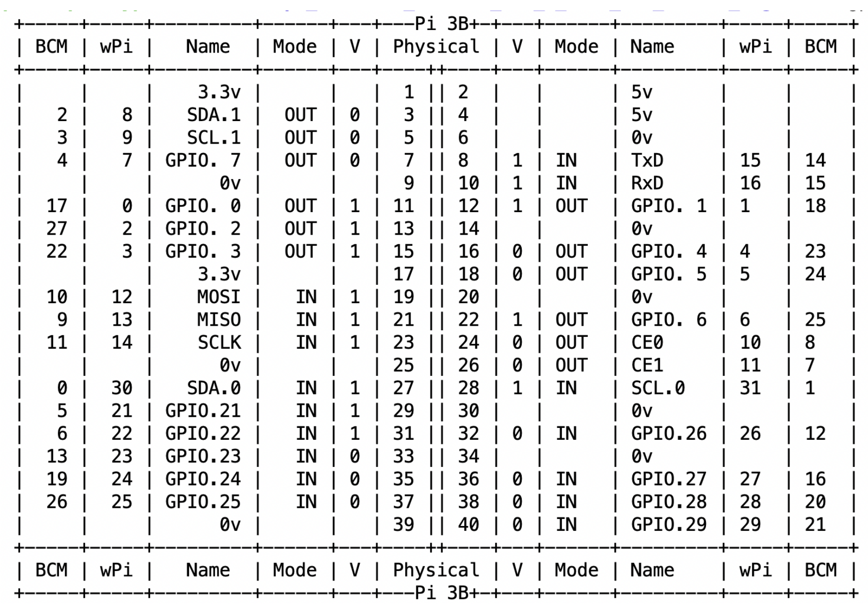


Figure 7.2: Circuit for 7 segment display with common cathode.

```
/*
* File name   : segment.c
* Description : display 0~9, A~F on 7-segment display
* Website     : www.adeept.com
* E-mail      : support@adeept.com
* Author      : Jason
* Date        : 2015/05/26
*/
#include <stdio.h>
#include <wiringPi.h>

typedef unsigned char uchar;

const uchar SegCode[17] = {0x3f,0x06,0x5b,0x4f,0x66,0x6d,0x7d,0x07,0x7f,0x6f,0x77,0x7c
    ,0x39,0x5e,0x79,0x71,0x80};

int main(void)
{
        int i;

        if(wiringPiSetup() < 0){ // setup wiringPi
                printf("wiringPi␣setup␣failed␣!\n");
                return -1;
        }

        for(i = 0; i < 8; i++){  // set pin mode as output(GPIO0~GPIO7)
                pinMode(i, OUTPUT);
        }

        while(1){
                for(i = 0; i < sizeof(SegCode)/sizeof(uchar); i++){ // display 0~9,A~F
                        digitalWriteByte(SegCode[i]);
                        delay(500);
                }
                digitalWriteByte(0x00);   //segment off
                delay(1000);
        }

        return 0;
}
```

You may notice that the leads are addressed using pins 0-7. Also, notice that `wiringPiSetup()` is used for setting up, which uses `wiringPi` pin numbers. Make sure that you are connecting to the correct pin number by checking the mapping using the command in th terminal: `$gpio readall`.

The output of `$gpio readall` is shown in Figure 7.3.



```
 +-----+-----+---------+------+---+---Pi 3B+-+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 |     |     |    3.3v |      |   |  1 || 2  |   |      | 5v      |     |     |
 |   2 |   8 |   SDA.1 |  OUT | 0 |  3 || 4  |   |      | 5v      |     |     |
 |   3 |   9 |   SCL.1 |  OUT | 0 |  5 || 6  |   |      | 0v      |     |     |
 |   4 |   7 | GPIO. 7 |  OUT | 0 |  7 || 8  | 1 | IN   | TxD     | 15  | 14  |
 |     |     |      0v |      |   |  9 || 10 | 1 | IN   | RxD     | 16  | 15  |
 |  17 |   0 | GPIO. 0 |  OUT | 1 | 11 || 12 | 1 | OUT  | GPIO. 1 | 1   | 18  |
 |  27 |   2 | GPIO. 2 |  OUT | 1 | 13 || 14 |   |      | 0v      |     |     |
 |  22 |   3 | GPIO. 3 |  OUT | 1 | 15 || 16 | 0 | OUT  | GPIO. 4 | 4   | 23  |
 |     |     |    3.3v |      |   | 17 || 18 | 0 | OUT  | GPIO. 5 | 5   | 24  |
 |  10 |  12 |    MOSI |   IN | 1 | 19 || 20 |   |      | 0v      |     |     |
 |   9 |  13 |    MISO |   IN | 1 | 21 || 22 | 1 | OUT  | GPIO. 6 | 6   | 25  |
 |  11 |  14 |    SCLK |   IN | 1 | 23 || 24 | 0 | OUT  | CE0     | 10  | 8   |
 |     |     |      0v |      |   | 25 || 26 | 0 | OUT  | CE1     | 11  | 7   |
 |   0 |  30 |   SDA.0 |   IN | 1 | 27 || 28 | 1 | IN   | SCL.0   | 31  | 1   |
 |   5 |  21 | GPIO.21 |   IN | 1 | 29 || 30 |   |      | 0v      |     |     |
 |   6 |  22 | GPIO.22 |   IN | 1 | 31 || 32 | 0 | IN   | GPIO.26 | 26  | 12  |
 |  13 |  23 | GPIO.23 |   IN | 0 | 33 || 34 |   |      | 0v      |     |     |
 |  19 |  24 | GPIO.24 |   IN | 0 | 35 || 36 | 0 | IN   | GPIO.27 | 27  | 16  |
 |  26 |  25 | GPIO.25 |   IN | 0 | 37 || 38 | 0 | IN   | GPIO.28 | 28  | 20  |
 |     |     |      0v |      |   | 39 || 40 | 0 | IN   | GPIO.29 | 29  | 21  |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+---Pi 3B+-+---+------+---------+-----+-----+
```

Figure 7.3: GPIO Pin Map.

7.2 4x4 Matrix Keyboard/Keypad

A 4x4 keypad module and its pin connections are shown in figure 7.4. Internally, it has 16 buttons arranged in matrix formation, as shown in Figure 7.5.

Listing 7.2 shows the code available at `Adeept_Ultimate_Starter_Kit_C_Code_for_RPi/13_matrixKeyboard/matrixKeyboard.c`. Pay extra attention to the row and column pin numbers to make the connection.

Listing 7.2: C code for Matrix Keyboard

```c
#include <wiringPi.h>
#include <stdio.h>

const int ROW[]    = {0, 1, 2, 3};
const int COLUMN[] = {4, 5, 6, 7};

int getKey(void)
{
        int i;
        int tmpRead;
        int rowVal = -1;
        int colVal = -1;
        char keyVal;

        for(i = 0; i < 4; i++){
                pinMode(COLUMN[i], OUTPUT);
                digitalWrite(COLUMN[i], LOW);
        }
```

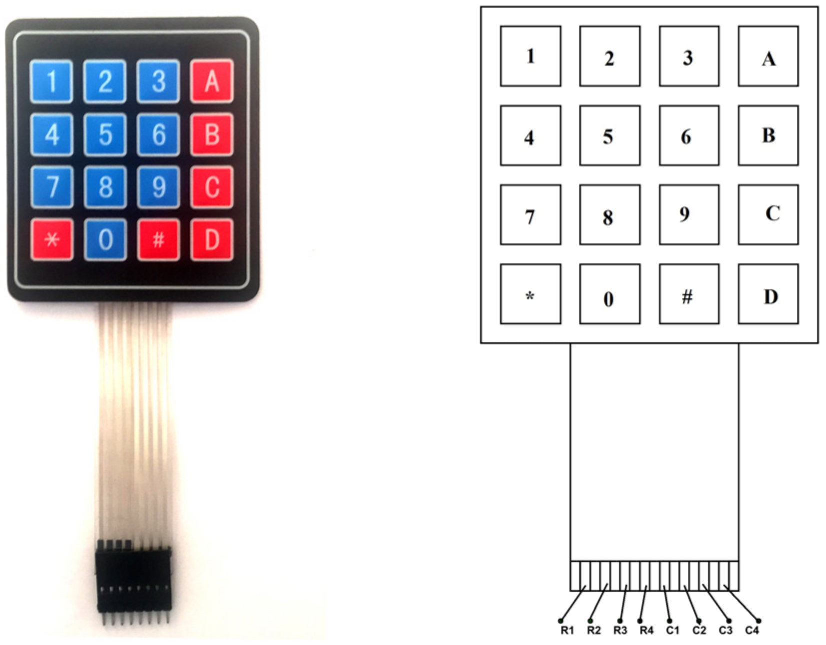


Figure 7.4: 4x4 Matrix Keyboard.

```
        for(i = 0; i < 4; i++){
                pinMode(ROW[i], INPUT);
                pullUpDnControl(ROW[i], PUD_UP);
        }

        for(i = 0; i < 4; i++){
                tmpRead = digitalRead(ROW[i]);
                if(tmpRead == 0){
                        rowVal = i;
                }
        }

        if(rowVal < 0 || rowVal > 3){
                return -1;
        }

        for(i = 0; i < 4; i++){
                pinMode(COLUMN[i], INPUT);
                pullUpDnControl(COLUMN[i], PUD_UP);
        }

        pinMode(ROW[rowVal], OUTPUT);
        digitalWrite(ROW[rowVal], LOW);

        for(i = 0; i < 4; i++){
                tmpRead = digitalRead(COLUMN[i]);
                if(tmpRead == 0){
                        colVal = i;
                }
        }
```

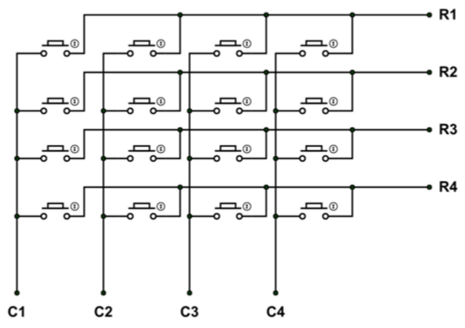


Figure 7.5: 4x4 Matrix Keyboard internal connections.

```
        if(colVal < 0 || colVal > 3){
                return -1;
        }

        //printf("%d, %d\n", rowVal, colVal);
        switch(rowVal){
                case 0:
                        switch(colVal){
                                case 0: keyVal = 0; break;
                                case 1: keyVal = 1; break;
                                case 2: keyVal = 2; break;
                                case 3: keyVal = 3; break;
                                default:
                                        break;
                        }
                        break;
                case 1:
                        switch(colVal){
                                case 0: keyVal = 4; break;
                                case 1: keyVal = 5; break;
                                case 2: keyVal = 6; break;
                                case 3: keyVal = 7; break;
                                default:
                                        break;
                        }
                        break;
                case 2:
                        switch(colVal){
                                case 0: keyVal = 8; break;
                                case 1: keyVal = 9; break;
                                case 2: keyVal = 10; break;
                                case 3: keyVal = 11; break;
                                default:
                                        break;
                        }
                        break;
                case 3:
                        switch(colVal){
                                case 0: keyVal = 12; break;
                                case 1: keyVal = 13; break;
                                case 2: keyVal = 14; break;
                                case 3: keyVal = 15; break;
                                default:
                                        break;

                        }
                        break;
                default:
                        break;
        }

        return keyVal;
}

int main(void)
{
        int i;
        int key = -1;

        if(wiringPiSetup() == -1){
                printf("setup wiringPi failed !\n");
                return -1;
        }

        while(1){
                key = getKey();
                if(key != -1){
                        switch(key){
                                case 0: printf("1\n"); break;
                                case 1: printf("2\n"); break;
                                case 2: printf("3\n"); break;
                                case 3: printf("A\n"); break;
                                case 4: printf("4\n"); break;
                                case 5: printf("5\n"); break;
                                case 6: printf("6\n"); break;
                                case 7: printf("B\n"); break;
                                case 8: printf("7\n"); break;
                                case 9: printf("8\n"); break;
                                case 10: printf("9\n"); break;
                                case 11: printf("C\n"); break;
                                case 12: printf("*\n"); break;
                                case 13: printf("0\n"); break;
                                case 14: printf("#\n"); break;
                                case 15: printf("D\n"); break;
                                default:
                                        break;
                        }
                }
                delay(200);
        }

        return 0;
}
```

Chapter 8

I2C Communication

In this chapter, we will study I2C. I2C on the RPi is implemented using the Broadcom Serial Controller (BSC), which supports 7-bit/10-bit addressing and bus frequencies of up to 400 kHz.

We will use ADXL345 Accelerometer in this example. The level of acceleration supported by a sensors output signal specifications is specified in $\pm g$. This is the greatest amount of acceleration the part can measure and accurately represent as an output. For example, the output of a $\pm 2g$ accelerometer is linear with acceleration up to $\pm 2g$. If it is accelerated at $4g$, the output may saturate.

1. We begin by enabling the I2C interface on the RPi by typing the following in terminal:
   ```
   $sudo raspi-config
   ```
   Choose Interfacing Options → I2C → Yes.

2. Check whether I2C is enabled. `/dev` is the location of device files. If I2C was enabled correctly, it will show up in `/dev/`. Type the following in terminal.
   ```
   $sudo ls /dev/i2c*
   ```
   Your output will be similar to:
   ```
   /dev/i2c-1
   ```
   Then check if the kernel module is loaded by issuing `lsmod` command, which outputs information for each loaded kernel module on a new line:
   ```
   $lsmod | grep i2c
   ```
   Your output will be similar to:
   ```
   i2c_bcm2835 16384 0
   i2c_dev 16384 0
   ```
   If those two modules are not loaded, we can use `modprobe` to load the modules in Linux Kernel.
   ```
   $modprobe i2c_dev
   $modprobe i2c_bcm2835
   ```

3. In the next step, we need to create the circuit as below:
   (a) Connect SCL on the RPi to SCL on the ADXL345
   (b) Connect SDA on the RPi to SDA in the ADXL345
   (c) Connect GND on the RPi to GND on the ADXL345
   (d) Connect 3.3V on the RPi to VIN on the ADXL345

   Refer Figure 8.1 for visual guidance.

4. The I^{2}C bus can be probed to detect connected devices by using the following command:
   ```
   sudo i2cdetect -y -r 1
   ```
   The output shows the I2C addresses of the attached devices. For example, when ADXL345 (`0x53`), MPU-6050 (`0x68`) and PCF8591T (`0x48`) are attached to the I2C bus, we get the following output as in Figure 8.2.

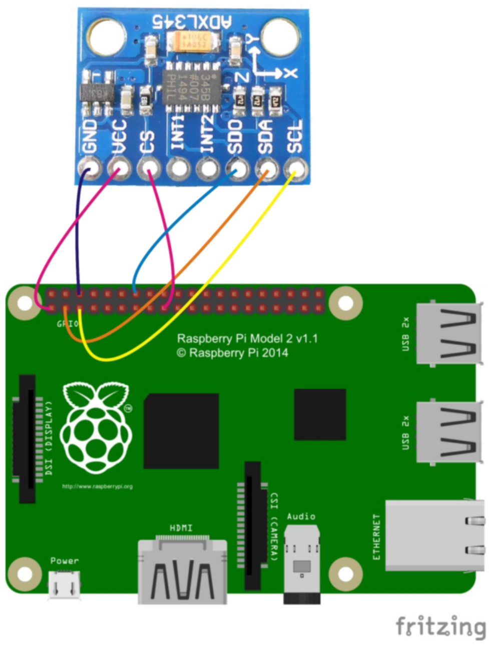


Figure 8.1: I2C Circuit Diagram.

```
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- 48 -- -- -- -- -- -- --
50: -- -- -- 53 -- -- -- -- -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- 68 -- -- -- -- -- -- --
70: -- -- -- -- -- -- -- --
```

Figure 8.2: I2C Detect Output.

5. Refer to the manual (ADXL345) for understanding the functionality and registers.
6. We will use the code that came with your Sensor kit. For ADXL345, the code resides in folder `Adeept_Ultimate_Starter_Kit_C_Code_for_RPi/25_ADXL345/`. Listing 8.1 shows the code.
7. The code uses `wiringPi`, for which you need to compile with `-lwiringPi`.
8. The code uses I2C wiringPi functions, the description of which are available at http://wiringpi.com/reference/i2c-library/
9. WiringPi implementation for I2C is available at https://github.com/WiringPi/WiringPi/blob/master/wiringPi/wiringPiI2C.c
10. Note that calibration should be performed for correct values, which can be set in the offset registers. https://learn.adafruit.com/adxl345-digital-accelerometer?view=all#programming

Listing 8.1: C code for ADXL345

```
#include <stdio.h>
#include <wiringPiI2C.h>

#define X_REG 0x32
#define Y_REG 0x34
#define Z_REG 0x36
```

```
short int axis_sample_average(int axis, int fd);
short int axis_sample(int axis,int fd);

int main(int argc, char *argv[])
{
        int fd = 0;
        short int data = 0;
        short int data2 = 0;
        int datasimple = 0;

        fd = wiringPiI2CSetup(0x53);

        datasimple = wiringPiI2CReadReg8(fd,0x31);
        wiringPiI2CWriteReg8(fd,0x31,datasimple|0xb);

        wiringPiI2CWriteReg8(fd,0x2d,0x08); //POWER_CTL
        usleep(11000);
        // erase offset bits
        wiringPiI2CWriteReg8(fd,0x1e,0);
        wiringPiI2CWriteReg8(fd,0x1f,0);
        wiringPiI2CWriteReg8(fd,0x20,0);
        usleep(11000);
        // calibrate X axis
        data = axis_sample_average(X_REG,fd);
        wiringPiI2CWriteReg8(fd,0x1e,-(data / 4));
        // calibrate Y axis
        data = axis_sample_average(Y_REG,fd);
        wiringPiI2CWriteReg8(fd,0x1f,-(data / 4));
        // calibrate Z axis
        data = axis_sample_average(Z_REG,fd);
        wiringPiI2CWriteReg8(fd,0x20,-((data - 256 ) / 4));

        usleep(100000);

        while(1){
                fprintf(stderr,"x:%f\n",axis_sample(X_REG,fd) / 128.0); // X
                fprintf(stderr,"y:%f\n",axis_sample(Y_REG, fd) / 128.0); // Y
                fprintf(stderr,"z:%f\n\n",axis_sample(Z_REG,fd) / 128.0); // Z
                usleep(100000);
        }

        return 0;
}

short int axis_sample(int axis,int fd)
{
        short int data = 0;
        short int data2 = 0;

        usleep(10000);
        data  =  wiringPiI2CReadReg8(fd,axis);
        data2 =  wiringPiI2CReadReg8(fd,axis+1);

        return ( (data2<<8)|data );
}

short int axis_sample_average(int axis, int fd)
{
        int c = 10;
        int value = 0;

        while(c--){
                value += axis_sample(axis, fd);
        }

        return ( value/10 );
}
```

Chapter 9

LCD Display

In this lesson, we will learn how to use a character display device LCD1602 on the Raspberry Pi platform. First, we make the LCD1602 display a string “Hello Geeks!”, then display “Adeept” and “www.adeept.com”.

LCD1602 is a kind of character LCD display. The LCD has a parallel interface, meaning that the microcontroller has to manipulate several interface pins at once to control the display. The interface consists of the following pins:

1. A register select (RS) pin that controls where in the LCD’s memory you’re writing data to. You can select either the data register, which holds what goes on the screen, or an instruction register, which is where the LCD’s controller looks for instructions on what to do next.
2. A Read/Write (R/W) pin that selects reading mode or writing mode.
3. An Enable pin that enables writing to the registers.
4. 8 data pins (D0-D7). The status of these pins (high or low) are the bits that you’re writing to a register when you write, or the values when you read.
5. There’s also a display contrast pin (Vo), power supply pins (+5V and Gnd) and LED Backlight (Bklt+ and BKlt-) pins that you can use to power the LCD, control the display contrast, and turn on or off the LED backlight respectively.

The Hitachi-compatible LCDs can be controlled in two modes: 4-bit or 8-bit. The 4-bit mode requires six I/O pins from the Raspberry Pi, while the 8-bit mode requires 10 pins. For displaying text on the screen, you can do almost everything in 4-bit mode. The example shows how to control a 2x16 LCD in 4-bit mode.

Then we need to create the circuit as below:

1. Connect VSS on the LCD to GND on the RPi
2. Connect VDD on the LCD to 3.3V on the RPi
3. Connect V0 on the LCD to the potentiometer
4. Connect RS on the LCD to GPIO24 on the RPi
5. Connect RW on the LCD to GND on the RPi
6. Connect E on the LCD to GPIO23 on the RPi
7. Connect D4 on the LCD to GPIO17 on the RPi
8. Connect D5 on the LCD to GPIO18 on the RPi
9. Connect D6 on the LCD to GPIO27 on the RPi
10. Connect D7 on the LCD to GPIO22 on the RPi
11. Connect A on the LCD to 5.0V on the RPi
12. Connect K on the LCD to GND on the RPi

Figure 9.1 shows the circuit diagram for a LCD1602 display.

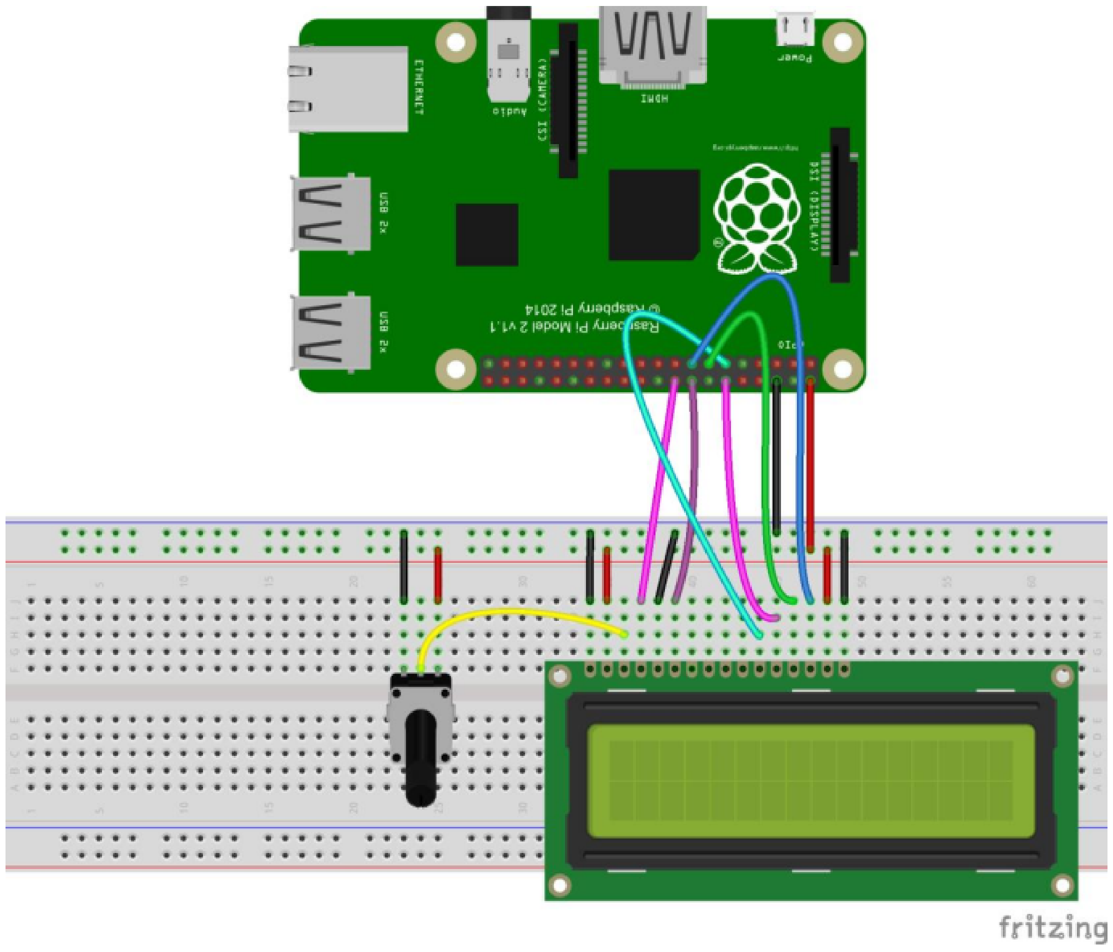


Figure 9.1: lcd1602.

Listing 9.1 shows the code available at
`Adeept_Ultimate_Starter_Kit_Python_Code_for_RPi/11_lcd1602.py`.

Listing 9.1: lcd1602.py

```
#!/usr/bin/env python

#
# based on code from lrvick and LiquidCrystal
# lrvic - https://github.com/lrvick/raspi-hd44780/blob/master/hd44780.py
# LiquidCrystal - https://github.com/arduino/Arduino/blob/master/libraries/
    LiquidCrystal/LiquidCrystal.cpp
#

from time import sleep

class Adafruit_CharLCD:

    # commands
    LCD_CLEARDISPLAY            = 0x01
```

```
LCD_RETURNHOME                    = 0x02
LCD_ENTRYMODESET              = 0x04
LCD_DISPLAYCONTROL            = 0x08
LCD_CURSORSHIFT               = 0x10
LCD_FUNCTIONSET               = 0x20
LCD_SETCGRAMADDR              = 0x40
LCD_SETDDRAMADDR              = 0x80

# flags for display entry mode
LCD_ENTRYRIGHT                = 0x00
LCD_ENTRYLEFT                 = 0x02
LCD_ENTRYSHIFTINCREMENT       = 0x01
LCD_ENTRYSHIFTDECREMENT       = 0x00

# flags for display on/off control
LCD_DISPLAYON                 = 0x04
LCD_DISPLAYOFF                = 0x00
LCD_CURSORON                  = 0x02
LCD_CURSOROFF                 = 0x00
LCD_BLINKON                   = 0x01
LCD_BLINKOFF                  = 0x00

# flags for display/cursor shift
LCD_DISPLAYMOVE               = 0x08
LCD_CURSORMOVE                = 0x00

# flags for display/cursor shift
LCD_DISPLAYMOVE               = 0x08
LCD_CURSORMOVE                = 0x00
LCD_MOVERIGHT                 = 0x04
LCD_MOVELEFT                  = 0x00

# flags for function set
LCD_8BITMODE                  = 0x10
LCD_4BITMODE                  = 0x00
LCD_2LINE                     = 0x08
LCD_1LINE                     = 0x00
LCD_5x10DOTS                  = 0x04
LCD_5x8DOTS                   = 0x00



def __init__(self, pin_rs=24, pin_e=23, pins_db=[17, 18, 27, 22], GPIO = None):
    # Emulate the old behavior of using RPi.GPIO if we haven't been given
    # an explicit GPIO interface to use
    if not GPIO:
        import RPi.GPIO as GPIO
    self.GPIO = GPIO
    self.pin_rs = pin_rs
    self.pin_e = pin_e
    self.pins_db = pins_db

    self.GPIO.setwarnings(False)
    self.GPIO.setmode(GPIO.BCM)
    self.GPIO.setup(self.pin_e, GPIO.OUT)
    self.GPIO.setup(self.pin_rs, GPIO.OUT)

    for pin in self.pins_db:
        self.GPIO.setup(pin, GPIO.OUT)
    self.write4bits(0x33) # initialization
    self.write4bits(0x32) # initialization
    self.write4bits(0x28) # 2 line 5x7 matrix
    self.write4bits(0x0C) # turn cursor off 0x0E to enable cursor
    self.write4bits(0x06) # shift cursor right

    self.displaycontrol = self.LCD_DISPLAYON | self.LCD_CURSOROFF | self.
        LCD_BLINKOFF

    self.displayfunction = self.LCD_4BITMODE | self.LCD_1LINE | self.LCD_5x8DOTS
    self.displayfunction |= self.LCD_2LINE

    """ Initialize to default text direction (for romance languages) """
    self.displaymode =  self.LCD_ENTRYLEFT | self.LCD_ENTRYSHIFTDECREMENT
    self.write4bits(self.LCD_ENTRYMODESET | self.displaymode) #  set the entry
        mode

    self.clear()


def begin(self, cols, lines):

    if (lines > 1):
            self.numlines = lines
            self.displayfunction |= self.LCD_2LINE
            self.currline = 0


def home(self):

    self.write4bits(self.LCD_RETURNHOME) # set cursor position to zero
    self.delayMicroseconds(3000) # this command takes a long time!


def clear(self):

    self.write4bits(self.LCD_CLEARDISPLAY) # command to clear display
    self.delayMicroseconds(3000)    # 3000 microsecond sleep, clearing the display
         takes a long time


def setCursor(self, col, row):

    self.row_offsets = [ 0x00, 0x40, 0x14, 0x54 ]

    if ( row > self.numlines ):
            row = self.numlines - 1 # we count rows starting w/0

    self.write4bits(self.LCD_SETDDRAMADDR | (col + self.row_offsets[row]))


def noDisplay(self):
    """ Turn the display off (quickly) """

    self.displaycontrol &= ~self.LCD_DISPLAYON
    self.write4bits(self.LCD_DISPLAYCONTROL | self.displaycontrol)
def display(self):
    """ Turn the display on (quickly) """

    self.displaycontrol |= self.LCD_DISPLAYON
    self.write4bits(self.LCD_DISPLAYCONTROL | self.displaycontrol)


def noCursor(self):
    """ Turns the underline cursor on/off """

    self.displaycontrol &= ~self.LCD_CURSORON
    self.write4bits(self.LCD_DISPLAYCONTROL | self.displaycontrol)


def cursor(self):
    """ Cursor On """

    self.displaycontrol |= self.LCD_CURSORON
    self.write4bits(self.LCD_DISPLAYCONTROL | self.displaycontrol)


def noBlink(self):
    """ Turn on and off the blinking cursor """

    self.displaycontrol &= ~self.LCD_BLINKON
    self.write4bits(self.LCD_DISPLAYCONTROL | self.displaycontrol)


def noBlink(self):
    """ Turn on and off the blinking cursor """

    self.displaycontrol &= ~self.LCD_BLINKON
    self.write4bits(self.LCD_DISPLAYCONTROL | self.displaycontrol)


def DisplayLeft(self):
    """ These commands scroll the display without changing the RAM """

    self.write4bits(self.LCD_CURSORSHIFT | self.LCD_DISPLAYMOVE | self.
        LCD_MOVELEFT)


def scrollDisplayRight(self):
    """ These commands scroll the display without changing the RAM """

    self.write4bits(self.LCD_CURSORSHIFT | self.LCD_DISPLAYMOVE | self.
        LCD_MOVERIGHT);


def leftToRight(self):
    """ This is for text that flows Left to Right """

    self.displaymode |= self.LCD_ENTRYLEFT
    self.write4bits(self.LCD_ENTRYMODESET | self.displaymode);


def rightToLeft(self):
    """ This is for text that flows Right to Left """
    self.displaymode &= ~self.LCD_ENTRYLEFT
    self.write4bits(self.LCD_ENTRYMODESET | self.displaymode)


def autoscroll(self):
    """ This will 'right justify' text from the cursor """

    self.displaymode |= self.LCD_ENTRYSHIFTINCREMENT
    self.write4bits(self.LCD_ENTRYMODESET | self.displaymode)


def noAutoscroll(self):
    """ This will 'left justify' text from the cursor """

    self.displaymode &= ~self.LCD_ENTRYSHIFTINCREMENT
    self.write4bits(self.LCD_ENTRYMODESET | self.displaymode)


def write4bits(self, bits, char_mode=False):
    """ Send command to LCD """

    self.delayMicroseconds(1000) # 1000 microsecond sleep

    bits=bin(bits)[2:].zfill(8)

    self.GPIO.output(self.pin_rs, char_mode)

    for pin in self.pins_db:
        self.GPIO.output(pin, False)

    for i in range(4):
        if bits[i] == "1":
            self.GPIO.output(self.pins_db[::-1][i], True)

    self.pulseEnable()

    for pin in self.pins_db:
        self.GPIO.output(pin, False)

    for i in range(4,8):
        if bits[i] == "1":
            self.GPIO.output(self.pins_db[::-1][i-4], True)

    self.pulseEnable()


def delayMicroseconds(self, microseconds):
    seconds = microseconds / float(1000000) # divide microseconds by 1 million for
         seconds
    sleep(seconds)


def pulseEnable(self):
    self.GPIO.output(self.pin_e, False)
    self.delayMicroseconds(1)               # 1 microsecond pause - enable pulse
        must be > 450ns
    self.GPIO.output(self.pin_e, True)
    self.delayMicroseconds(1)               # 1 microsecond pause - enable pulse
        must be > 450ns
    self.GPIO.output(self.pin_e, False)
    self.delayMicroseconds(1)               # commands need > 37us to settle


def message(self, text):
    """ Send string to LCD. Newline wraps to second line"""

    for char in text:
        if char == '\n':
            self.write4bits(0xC0) # next line
        else:
            self.write4bits(ord(char),True)

def loop():
    lcd = Adafruit_CharLCD()
    while True:
            lcd.clear()
            lcd.message("␣LCD␣1602␣Test␣\n123456789ABCDEF")
            sleep(2)
            lcd.clear()
            lcd.message("␣␣␣Hello,␣geeks␣!\nHello␣World␣!␣:)")
            sleep(2)
            lcd.clear()
            lcd.message("Welcom␣to␣--->\n␣␣adeept.com")
            sleep(2)

if __name__ == '__main__':
    loop()
```

Chapter 10

Servo Motor

In this chapter, we will discuss Servo Motors and learn how to control it with the Raspberry Pi.

The Servo motor is a type of geared motor that can rotate 180 degrees. It is controlled by sending pulses signal from your microcontroller. These pulses tell the servo what position it should move to. The Servo motor consists of a shell, circuit board, non-core motor, gear and location detection modules. Its working principle is as follow:

1. The Raspberry Pi sends a PWM signal to the servo motor.
2. This signal is processed by an IC on circuit board to calculate the rotation direction to drive the motor, and then this driving power is transferred to the swing arm by a reduction gear.
3. The position detector returns the location signal to gauge whether the set location is reached or not.

The relationship between the rotation angle of the servo and pulse width is shown in Figure 10.1.

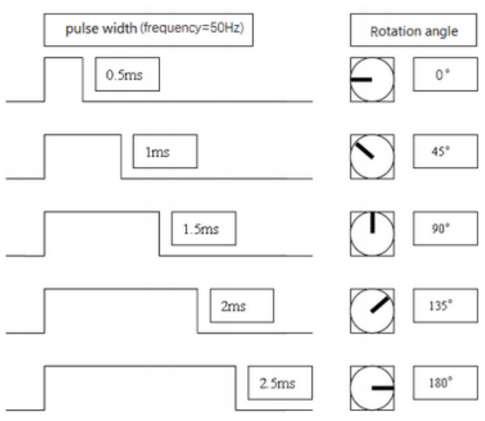
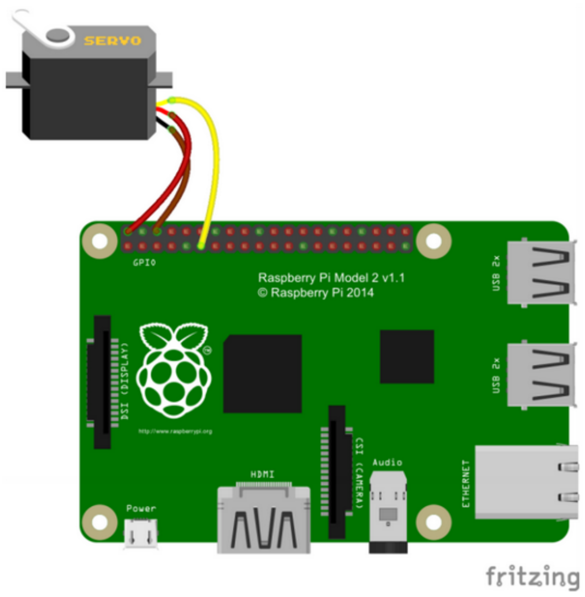


Figure 10.1: Servo Motor Principle.

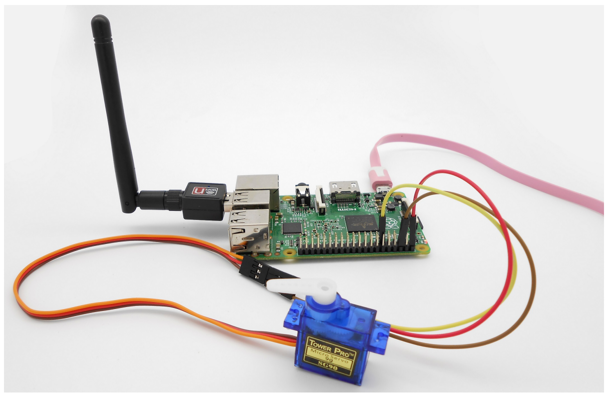
There are three pins in a Servo motor, where you should use 5V for power supply. The color coding of wiring of the servo can be of three different types as shown in Table 10.1.

Pin Number	**Signal Name**	**(Futaba)**	**(JR)**	**(Hitec)**
1	Ground	Black	Brown	Black
2	Power Supply	Red	Red	Red or Brown
3	Control Signal	White	Orange	Yellow or White

Table 10.1: Color coding for the wiring of Servo



(a) Circuit Connection.



(b) Servo Connected with Raspberry Pi.

Figure 10.2: Servo Connection with Raspberry Pi.

In the next step, you should connect the Servo motor with the Raspberry Pi as shown in Figure 10.2, using the color code in Table 10.1.

The script, as shown in Listing 10.1, is available at:
`/home/Adeept_Ultimate_Starter_Kit_C_Code_for_RPi/23_servo/servo.c`.
It generates software PWM signals for moving the Servo clockwise and anticlockwise.

Listing 10.1: Servo Motor Code

```
#include <stdio.h>
#include <wiringPi.h>

#define  Servo   0

void servo(int angle) //500~2500
{
        digitalWrite(Servo, 1);
        delayMicroseconds(angle);
        digitalWrite(Servo, 0);
        delayMicroseconds(20000-angle);
}

int main(void)
{
        int i, j;

        if(wiringPiSetup() < 0){
                printf("wiringPi␣setup␣error!\n");
                return -1;
        }

        pinMode(Servo, OUTPUT);

        while(1){
                servo(500);
                delay(500);
                for(i=500; i <=2500; i=i+500){
                        servo(i);
                        printf("i␣=␣%d\n", i);
                        delay(500);
                }
                servo(2500);
                delay(500);
                for(i=2500; i >=500; i=i-500){
                        servo(i);
                        printf("............i␣=␣%d\n", i);
                        delay(500);
                }
        }

        return 0;
}
```