keyestudio WiKi

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Nov 29, 2023

KS0564 KEYESTUDIO MOTION SENSING GLOVE GESTURE CONTROL SMART CAR FOR ARDUINO

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About Keyestudio

Keyestudio is a best-selling brand owned by KEYES Corporation. Our product contains Arduino development boards, expansion boards, sensors and modules, Raspberry Pi, micro: bit expansion boards as well as smart cars, which can help customers at any level to learn about Arduino.

Notably, all of our products are in line with international quality standards and are greatly appreciated in a broad menu of different markets across the world.

Welcome to check out more contents from our official website:

http://www.keyestudio.com

Obtain Information and After-sales Service

1. Motion Sensing GloveGesture Control Smart Car for Arduino Download address:

   https://fs.keyestudio.com/KS0564

2. If something is found missing or broken, or you have some difficulty learning the kit, please feel free to contact us. Welcome to send email to us: service@keyestudio.com

3. We will endeavor to update projects and products continuously from your sincere advice! Thanks!

Warning

1. This product contains pins, please be careful not to be stabbed, so please keep out of reach of children under 7.

2. This product contains conductive parts (control board and electronic module). Please operate according to the requirements of tutorials. Improper operation may damage parts due to overheating. Do not touch and immediately disconnect the circuit power.

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ON OFF
9V CELL
CGS
USB
D7
D8
Keyestudio
DX-BT24
BLE5.1
MPU6050

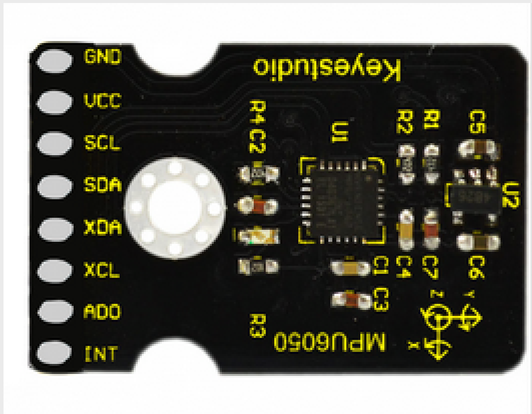
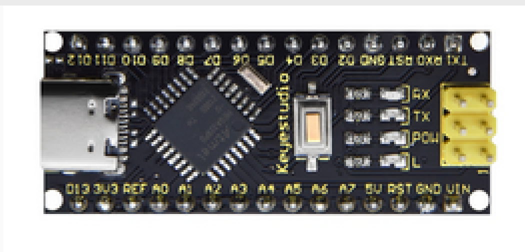
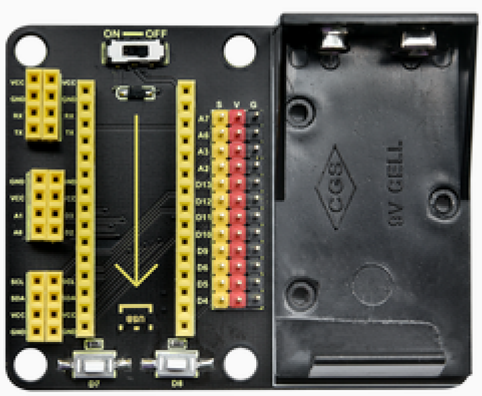
CHAPTER

ONE

KIT LIST

When you receive this product, please check according to Kit List to ensure that all components are intact.

If something is found missing, please contact us immediately.

NO.	PIC	Specification	QNT
1		MPU6050 Module	1
2		NANO PLUS Development Board	1
3		DX-BT24 V5.1 BLE	1
4		NANO Expansion Board	1
5		Half-Finger Gloves	1
6		USB Cable	1

CHAPTER TWO

INTRODUCTION

Based on MPU6050, this motion sensing glove is capable to recognize several directions of gestures. Compared with traditional operation mode like buttons or sliding, gestures allow you to control your devices at will.

This glove connects with Mecanum cars, robot arms and biped robots via BT24 Bluetooth, so that you can manipulate various movements (the advance of small cars, gripper of robot arms, and walking of robots) only by simple gestures.

Besides, it is easy to install. You just need to splice several modules together. And extra modules can be connected to the expansion board for easier control.

To bring you a better experience on intelligence and convenience of gesture control, multiple Arduino C language projects are prepared for you. In these projects, we will start from lighting up an LED to gesture control to ensure that you get started easily to master this skill.

CHAPTER

THREE

FEATURES

1. Powerful function: It is able to recognize different directions.
2. Simple installation: You need to splice several modules together without welding circuit.
3. Strong extensibility: It can attach additional sensors on the expansion board with commonly used interfaces.
4. Basic programming learning: couple with C language of Arduino IDE.

CHAPTER

FOUR

PARAMETERS

Working voltage: 5V

Battery voltage: 9V

Maximum current output: 20mA (9V battery)

Maximum power dissipation: 0.18W

BT communication distance: 40M (in open space)

BT working frequency: 2.4GHz ISM frequency band

Working temperature: –10°C ~ +65°C

CHAPTER

FIVE

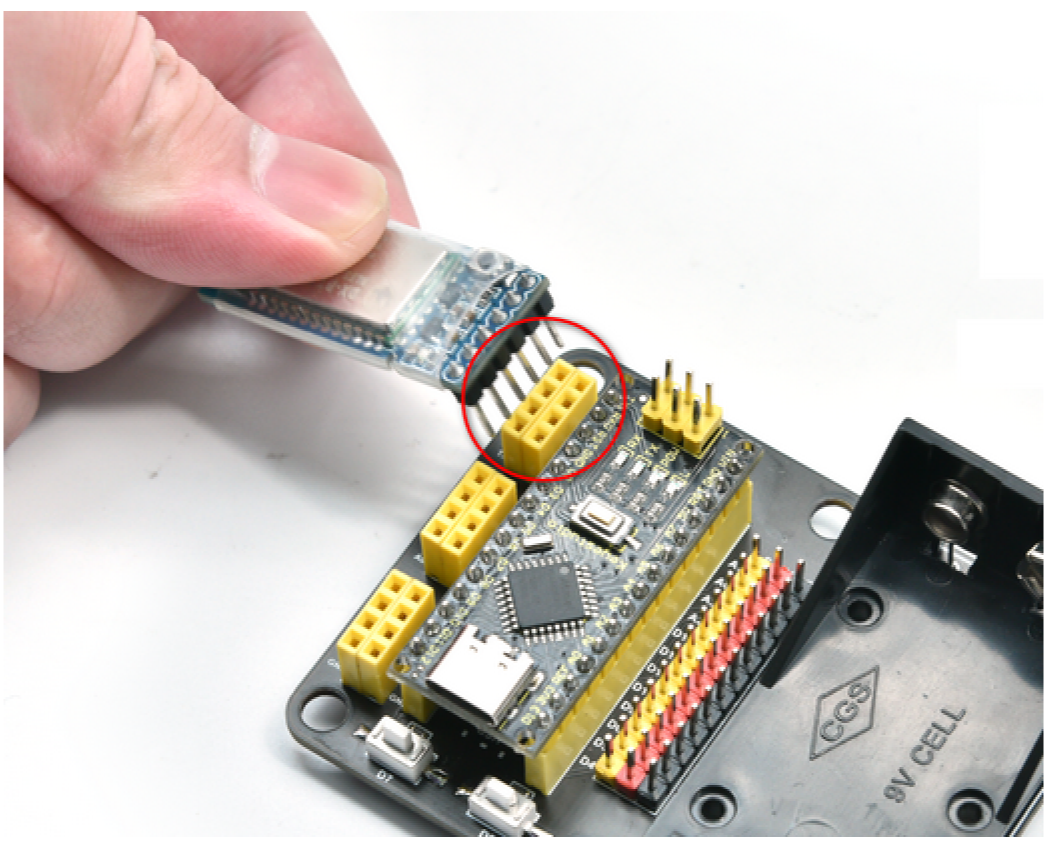
ATTACHMENT: INSTALLATION STEPS

Step1

The kit list excludes 9V battery

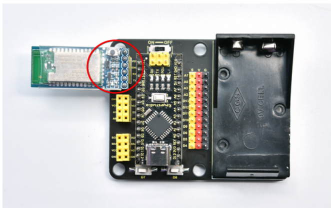
Step2

Connect Arduino NANO mainboard to the expansion board according to the array on it. Install BT module on the expansion board as follows:



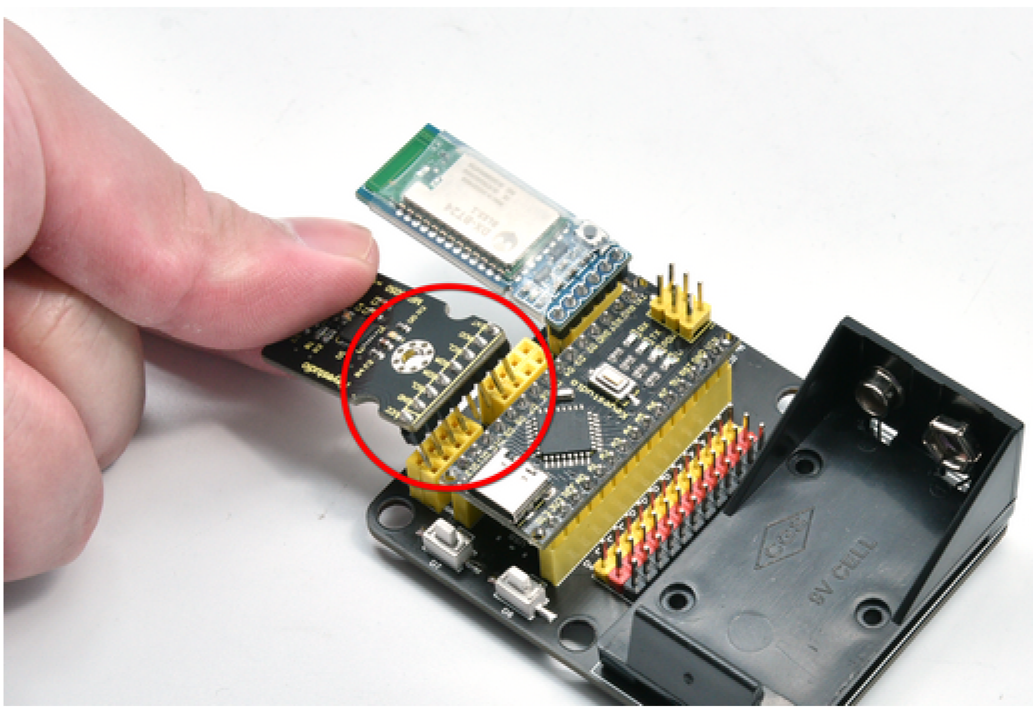
Step3

(GND–GND) (VCC–VCC) (TX–RX) (RX–TX)



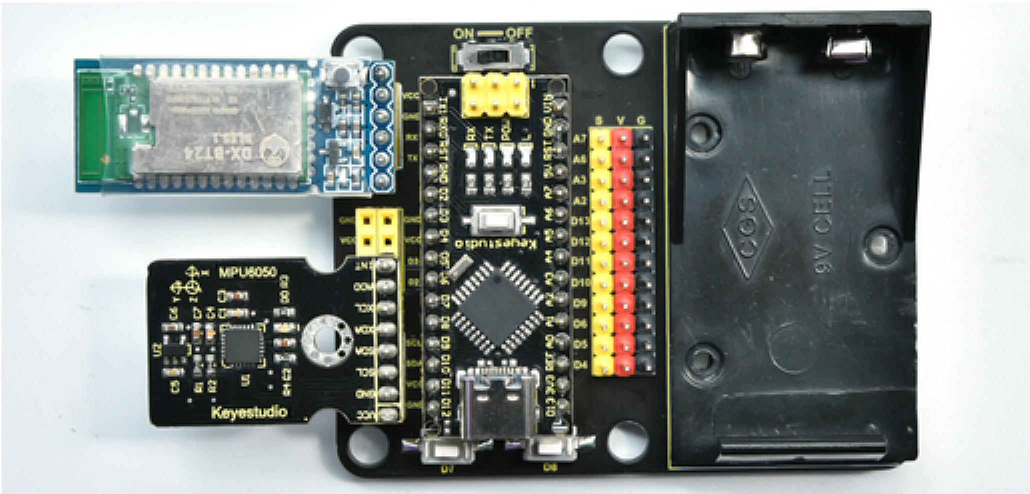
Step4

Install MPU6050 module on the expansion boardas follows



Step5

(GND–GND) (VCC–VCC) (SDA–SDA)(SCL–SCL)



Step6

Uncover the double-side adhesive foam tape behind the board and stick it to the back of one glove. Press to keep it steady.

Step7

Installation is complete.

CHAPTER

SIX

PROJECTS

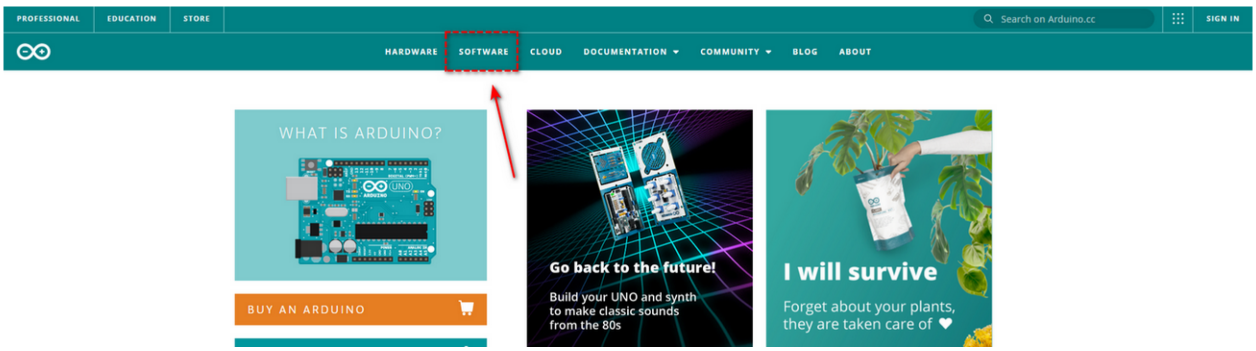
Note: G and GND on the expansion board are negative poles to connect with G, GND and - on sensors, while V and VCC are positive poles to connect with 5V power interfaces like V, VCC and +.

6.1 Install Development Software and Driver

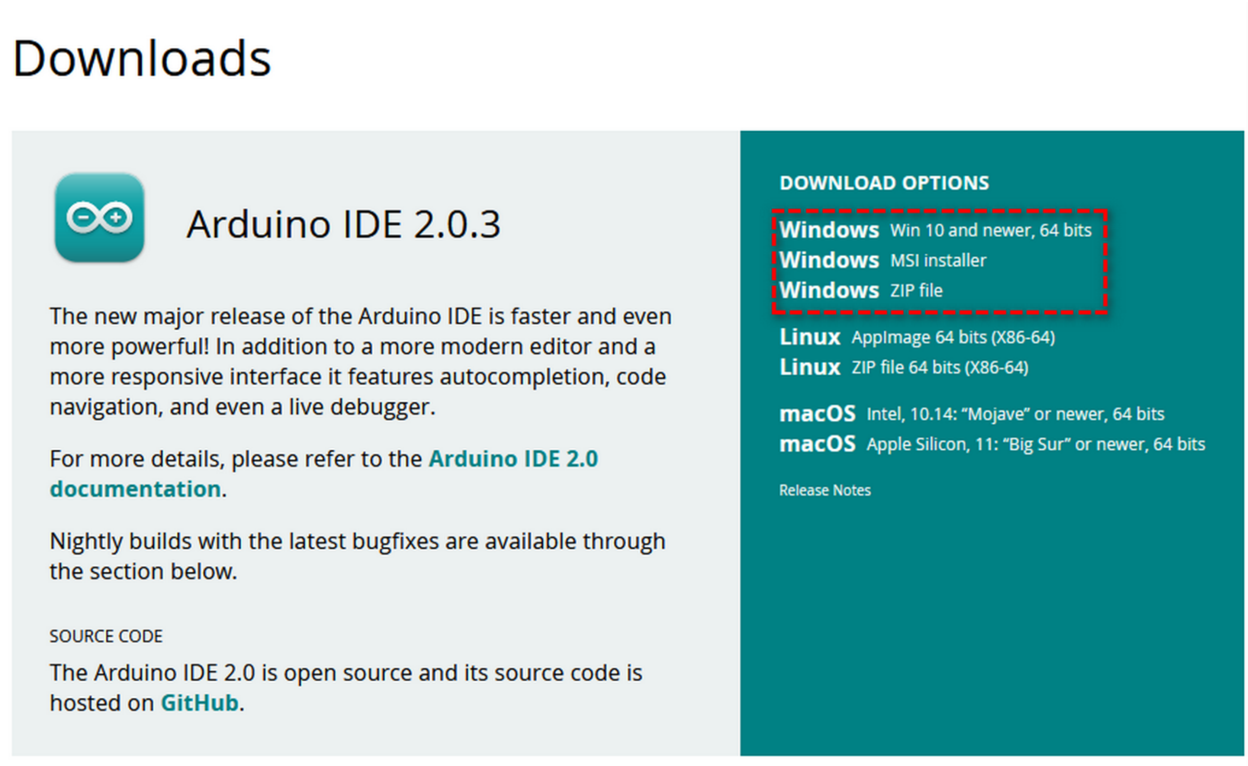
6.1.1 Install Arduino IDEWindows

Download the latest version of Arduino IDE: https://www.arduino.cc/

Click SOFTWARE on the upward side of the page:

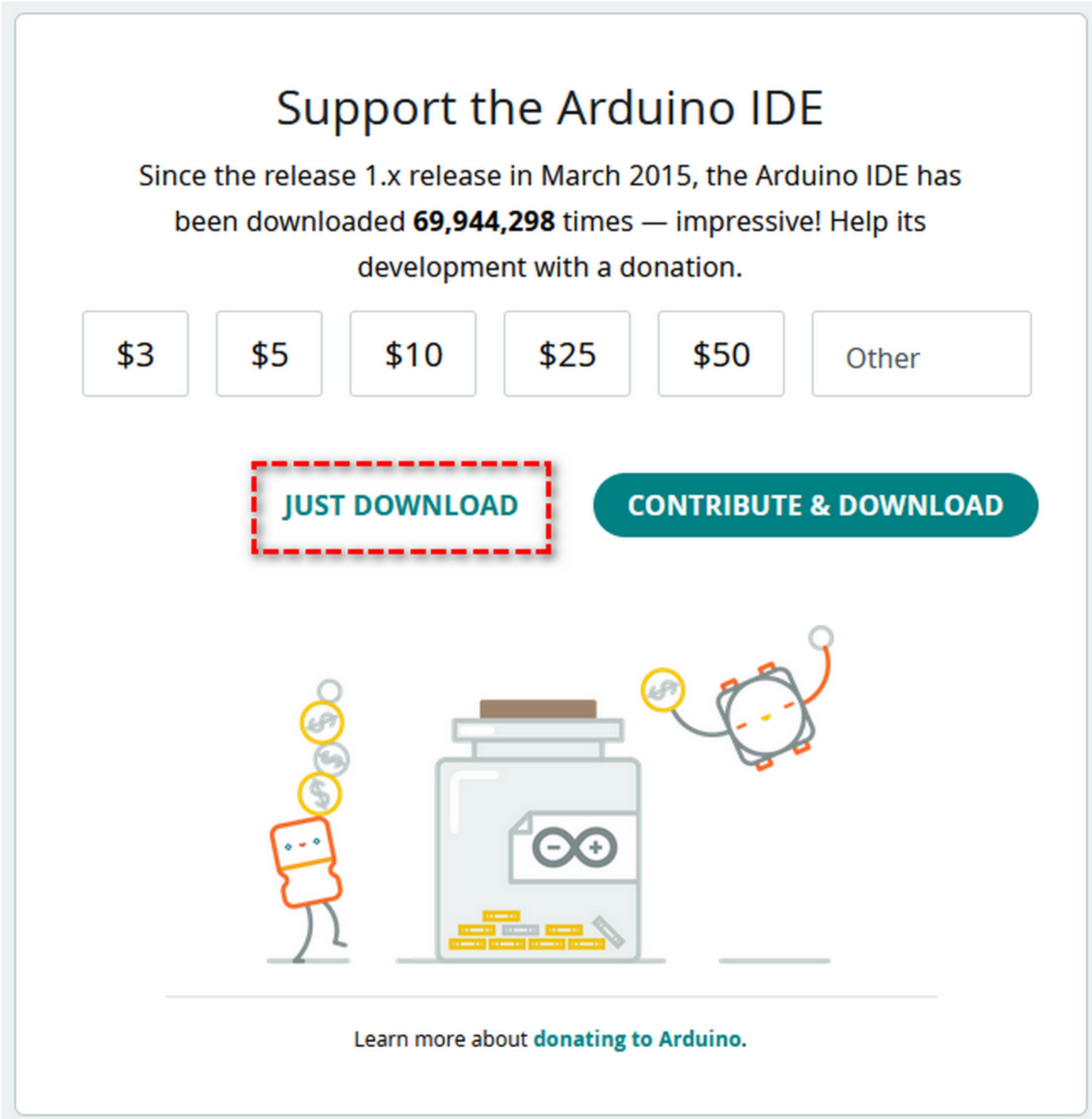


Select a compatible version.



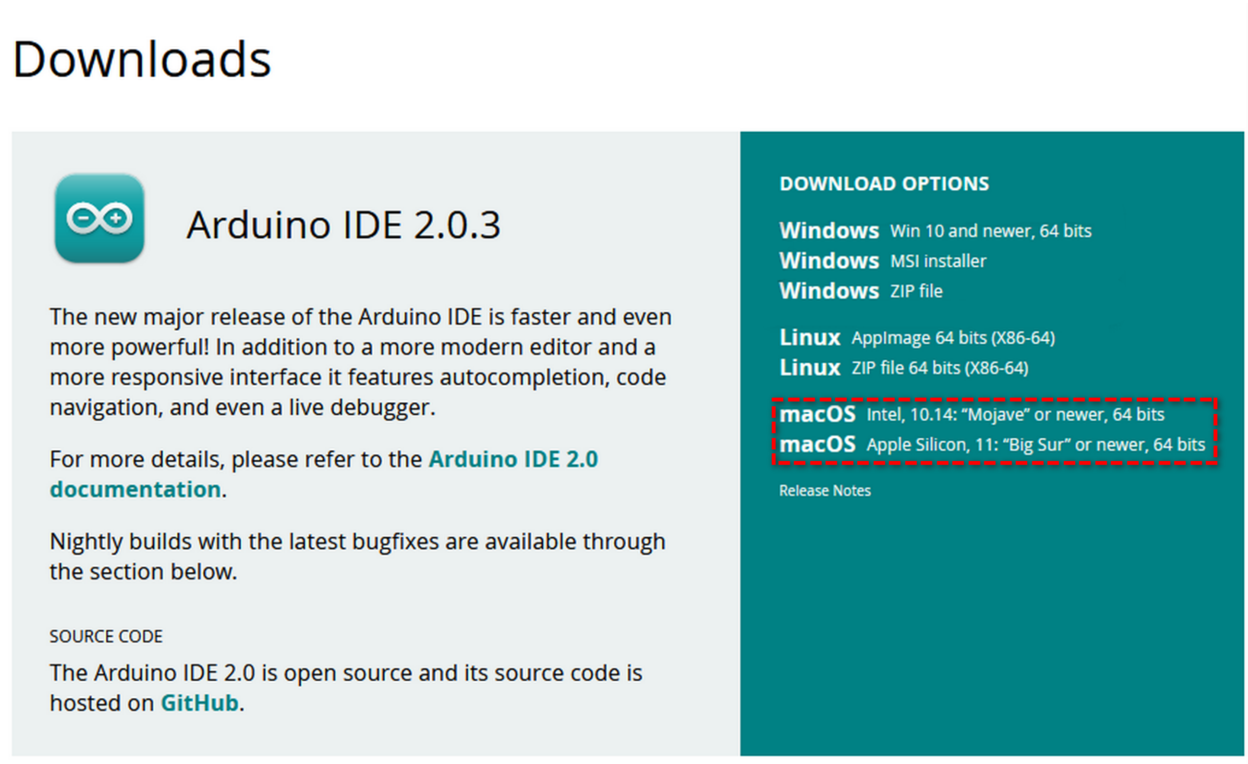
Two versions are included in Windows system: for installing and for downloading(a zipped file, directly unzip it to use without installing).

Click JUST DOWNLOAD.

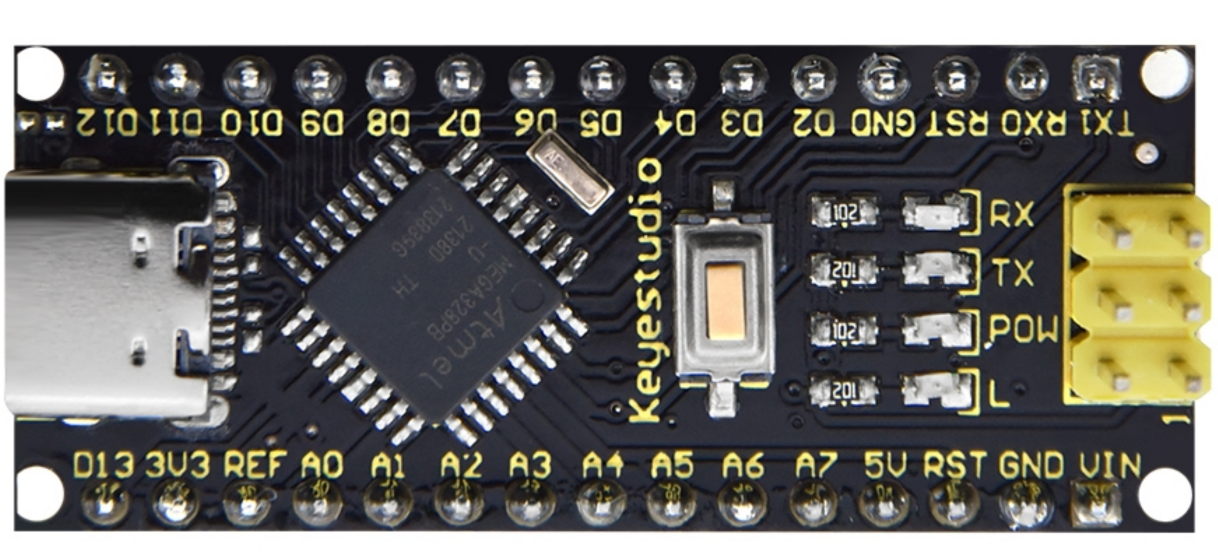

Support the Arduino IDE
Since the release 1.x release in March 2015, the Arduino IDE has been downloaded 69,944,298 times — impressive! Help its development with a donation.
$3
$5
$10
$25
$50
Other
JUST DOWNLOAD
CONTRIBUTE & DOWNLOAD
Learn more about donating to Arduino.

6.1.2 Install Arduino IDEMAC

Different Arduino IDE is need for different system



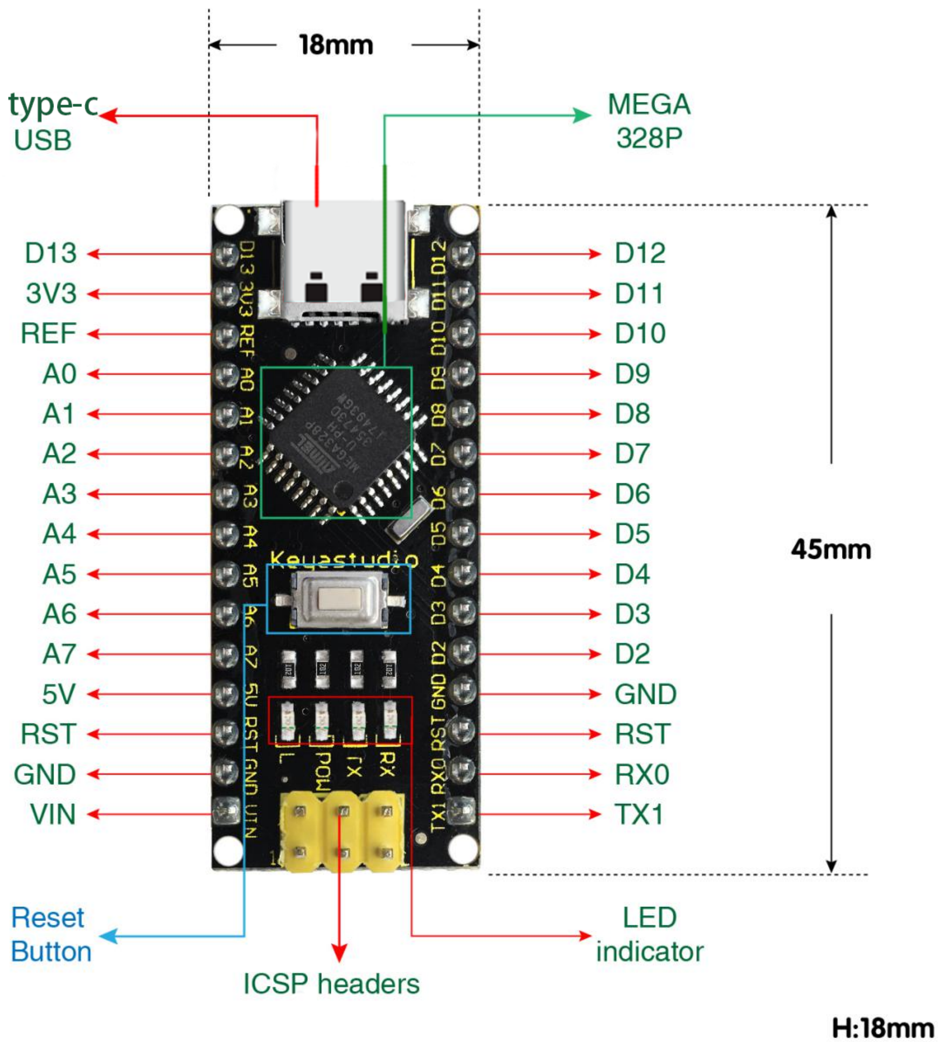
6.1.3 NANO PLUS Development Board

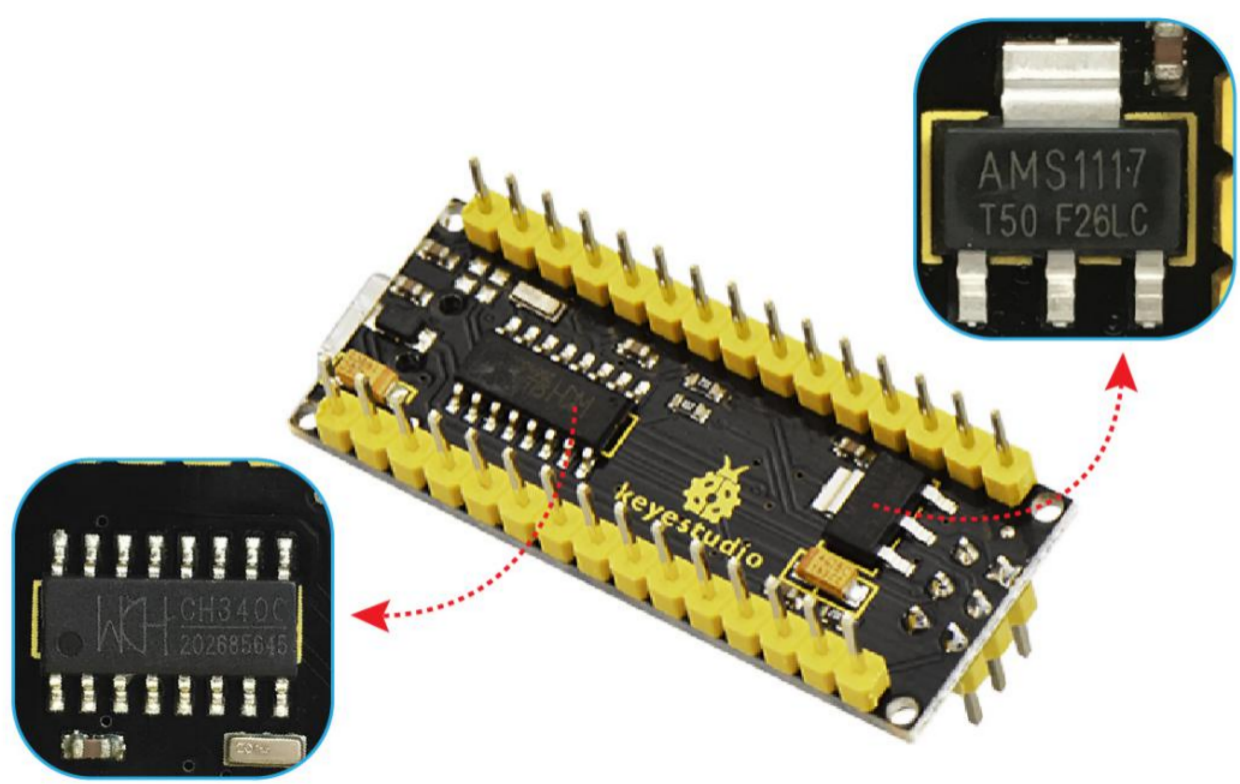


The processor core and USB-to-serial port chip of this board respectively adopt ATMEGA328P-AU and CH340. Compared with ARDUINO NANO, their using methods are exactly the same except driver installation.

It is comprised of 14 channel digital I/O interfaces (six of them are used as PWM outputs), 8 channel analog input interfaces, a 16MHz crystal oscillator, a Type-C USB port, ICSP headers and a RESET button.

ICSP headers are used for burning firmwares on ATMEGA328P-AU. When using, we power it via Type-C USB or VIN GND (DC 7-12V) pin.





It supports MCU, and connects pin Vin and GND (DC 7-12V) ports by a USB power supply to operate.

Interface descriptions:

NO.	Port Name	Description
1	ICSP Headers	They consist of MOSI, MISO, SCK, RESET, VCC and GND, commonly called SPI (Serial Peripheral Interface). They burn firmwares on ATMEGA328P-AU if connecting with computer.
2	LED indicatorRX	It is used for serial communication. RX indicator will blink if the board receives messages.
3	LED indicatorTX	It is used for serial communication. TX indicator will blink if the board sends messages.
4	LED indicatorPOW	LED will light up if the control board starts to work. Otherwise, the indicator goes off.
5	LED indicatorL	When D13 pin is at a high level, LED lights up. On the contrary, it goes off.
6	RX0(D0)TX1(- D13	14 digital I/O pins (D0-D13) are included, six of which are used as PWM outputs. These are digital input pins for logic values (0 or 1).
7	RST	It externally connects buttons used as Reset Button.
8	ATMEGA328P AU	This MCU is seen as the brain of the board. For more details, please refer to the data sheet.
9	Type-C USB	It powers the control board and uploads programs when connecting to computer.
10	3V3	It provides an output voltage of 3.3V.
11	REF	This analog pin sets the external reference voltage (0V to 5V) as the limit of analog input.
12	A0-A7	A0-A7 are eight analog pins.
13	5V	It is an 5V voltage I/O pin.
14	GND	It is the negative pole of power supply and connects with ground.
15	VIN	It powers the board via an external input voltage of DC 7-12V.
16	Reset Button	This button is able to reset the control board.
17	CH340	It is a USB-to-serial port chip to convert computer USB signal to serial signal.
18	AMS1117	It powers the mainboard by converting the voltage of external input DC 7-12V to DC 5V.

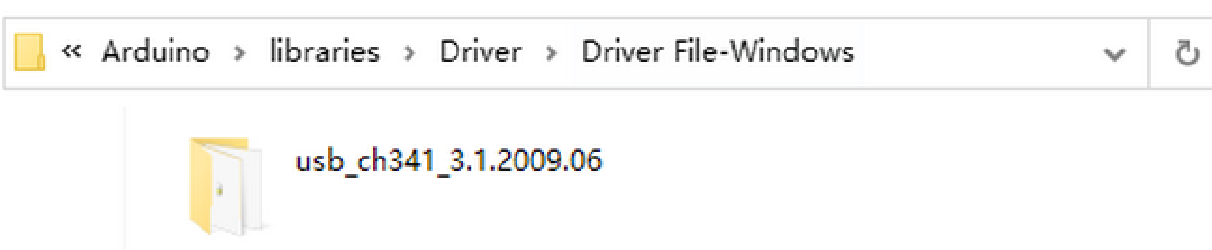
6.1.4 Install Development Board Driver

Detailed Usage for Windows System

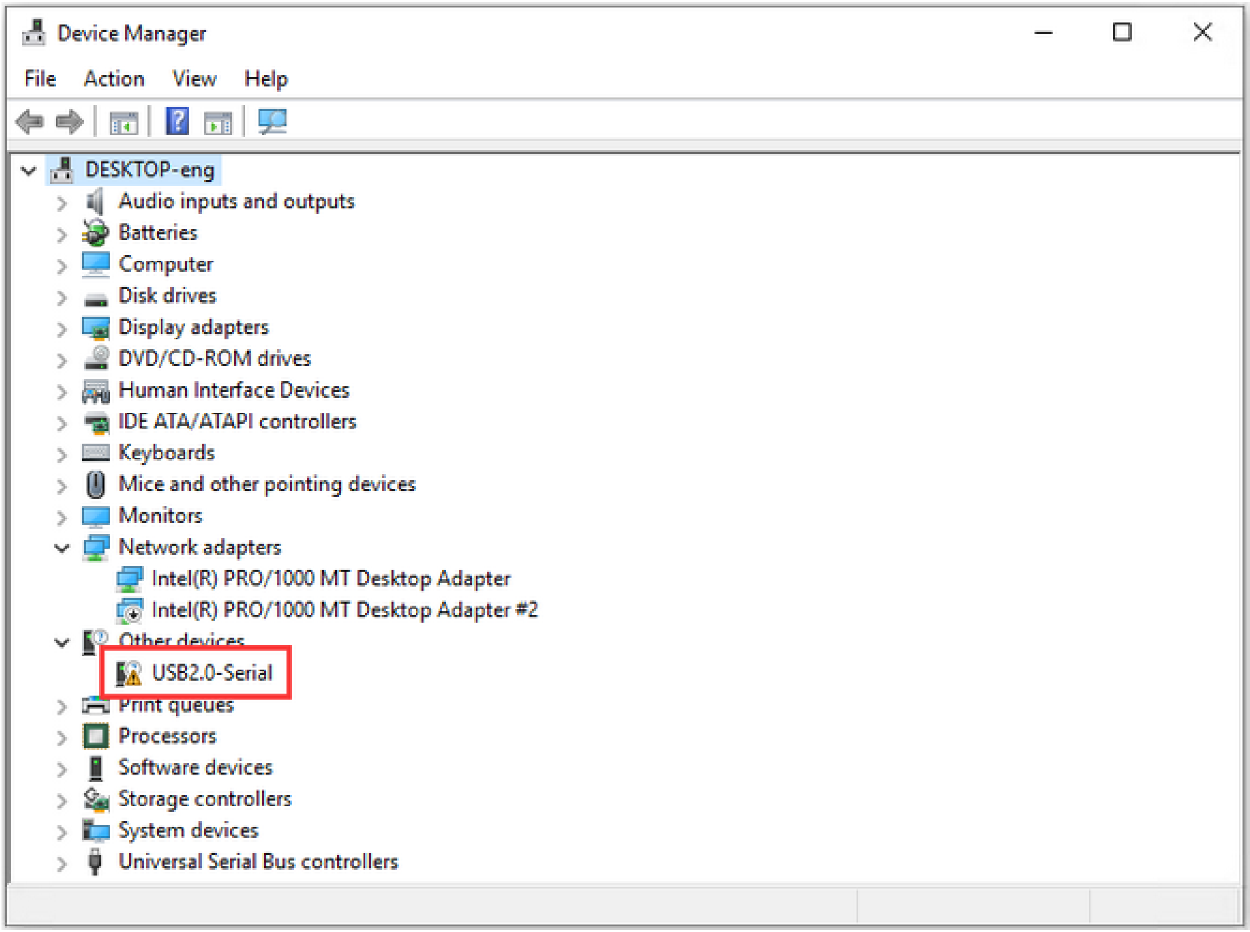
Connect the control board to computer via USB cable.

If your computer is Windows10 System, it will install the driver automatically. If it is Windows7 System, you need to operate manually.

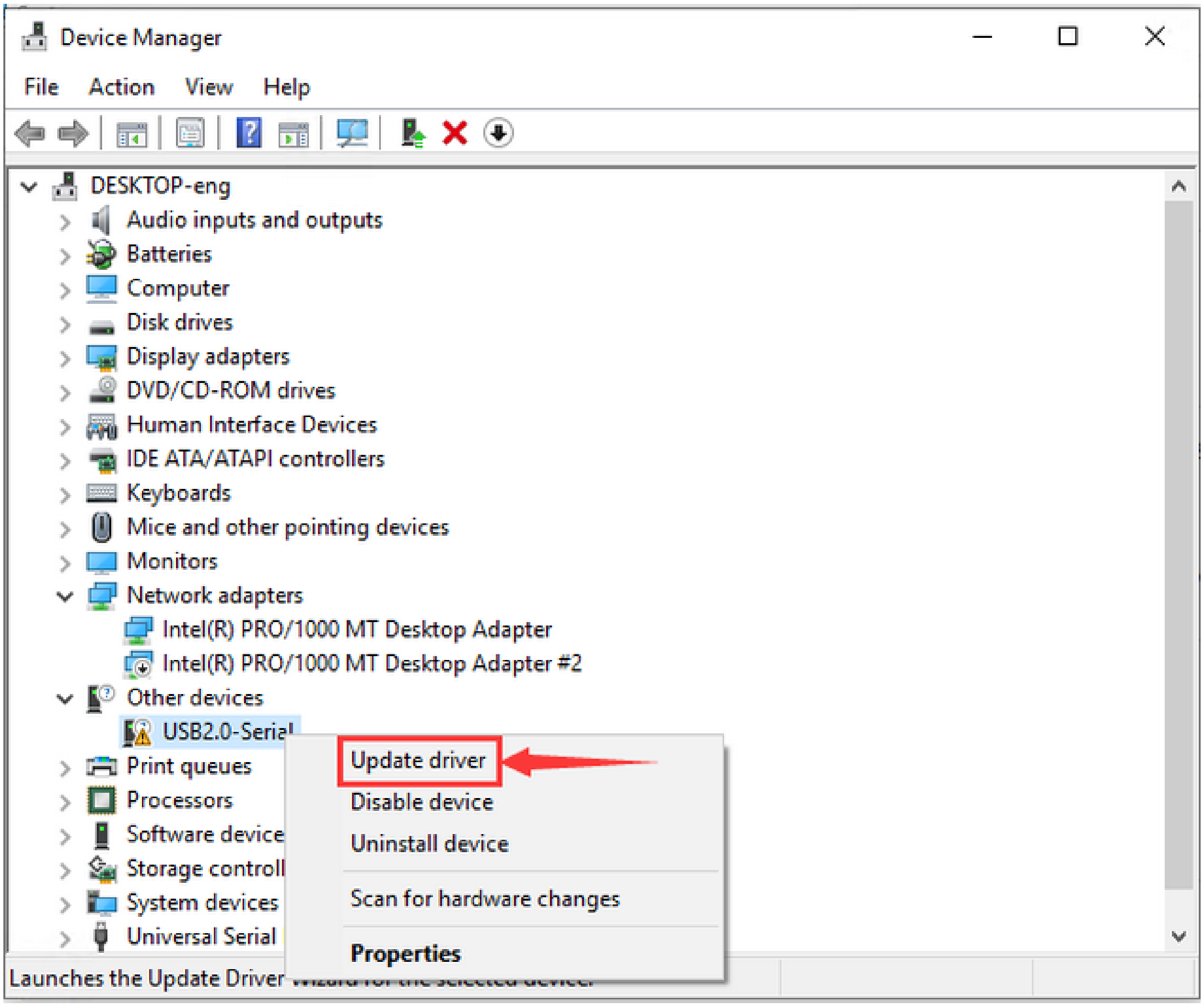
The USB-to-serial port chip of the board adopts CH340, and you need to install the chip driver whose file is usb_ch341_3.1.2009.06.



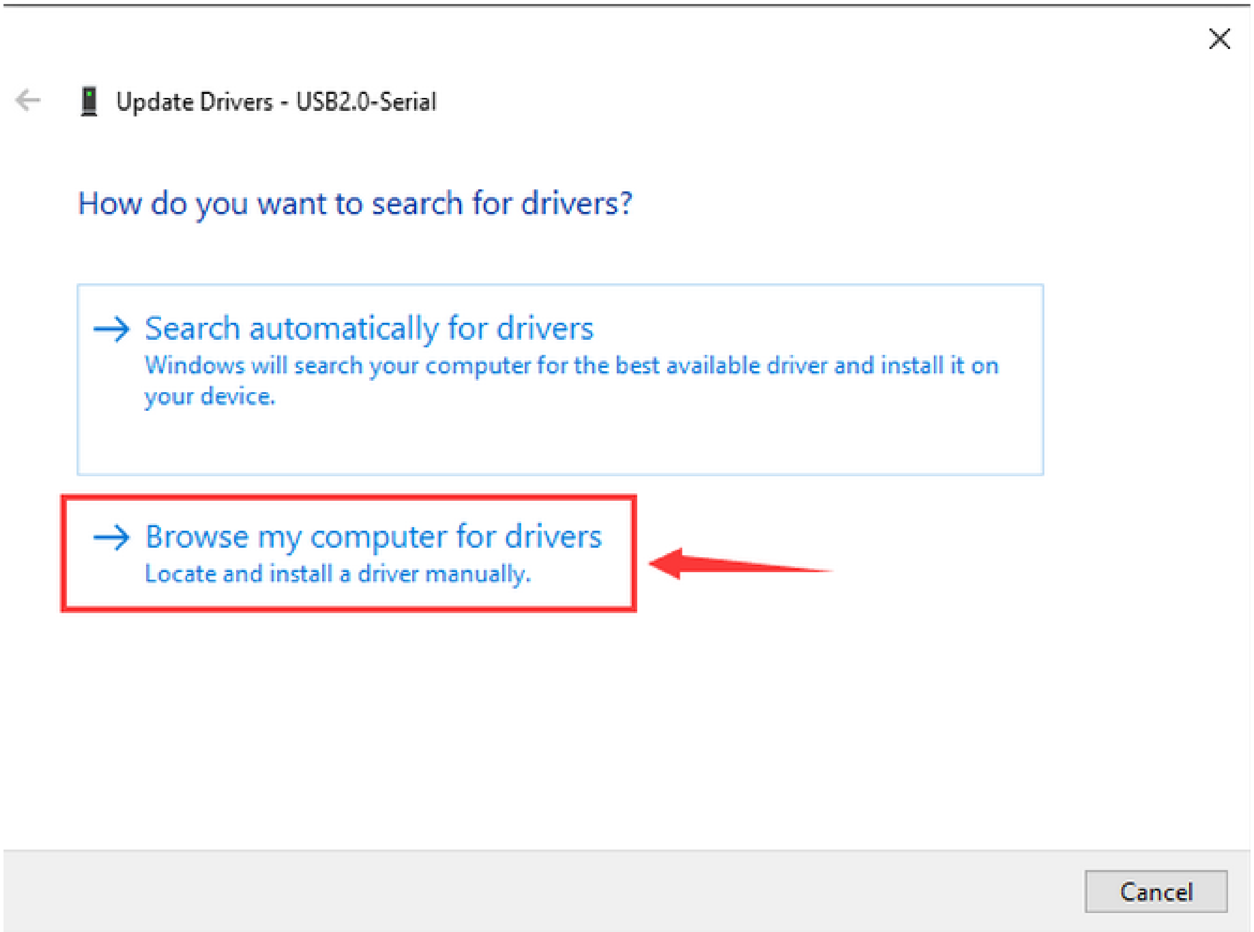
If it is the first time for the control board to connect to computer, please click Computer – Properties – Device Manager:



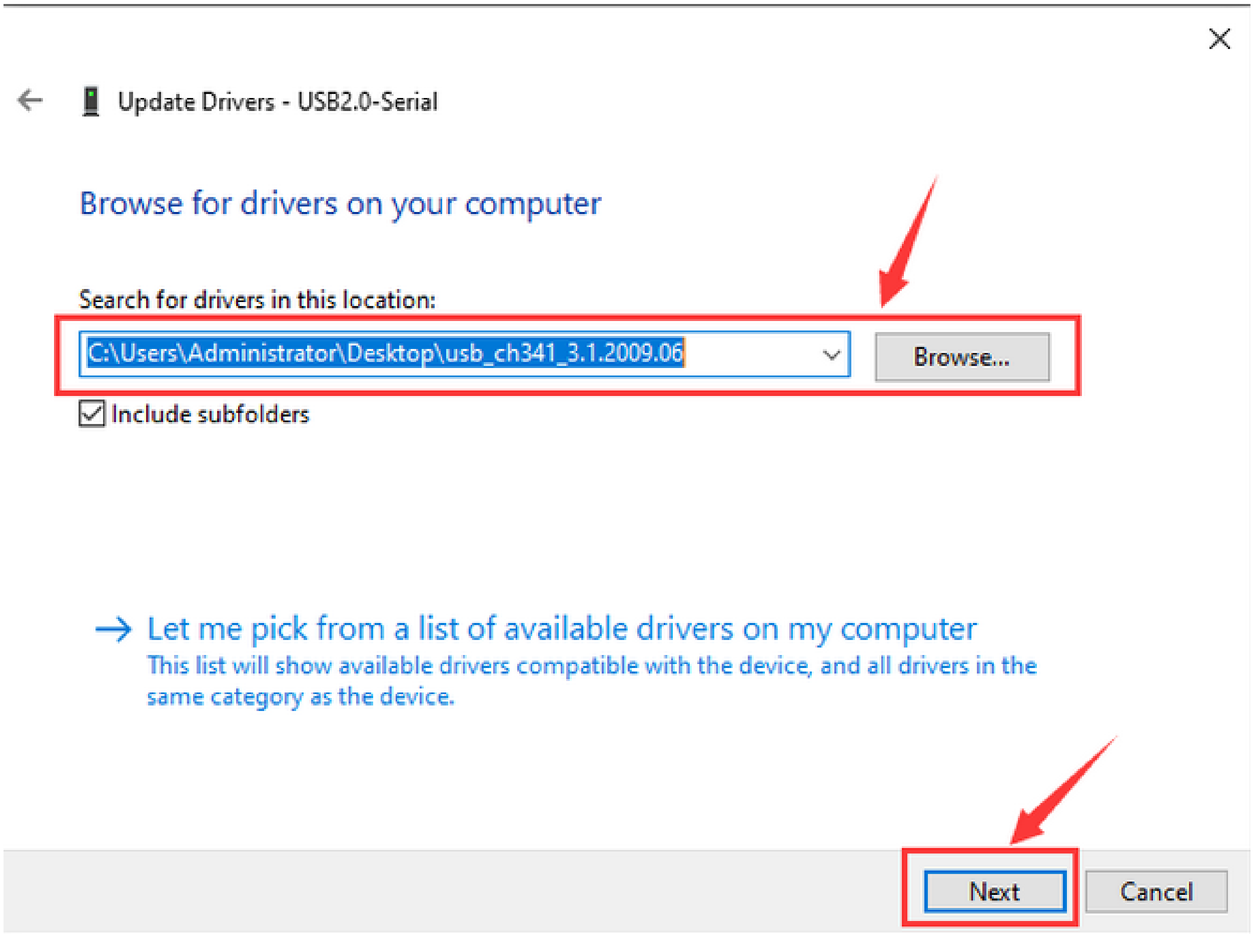
Click USB Serial to select“Update Driver”.



Select"browse my computer for drivers".

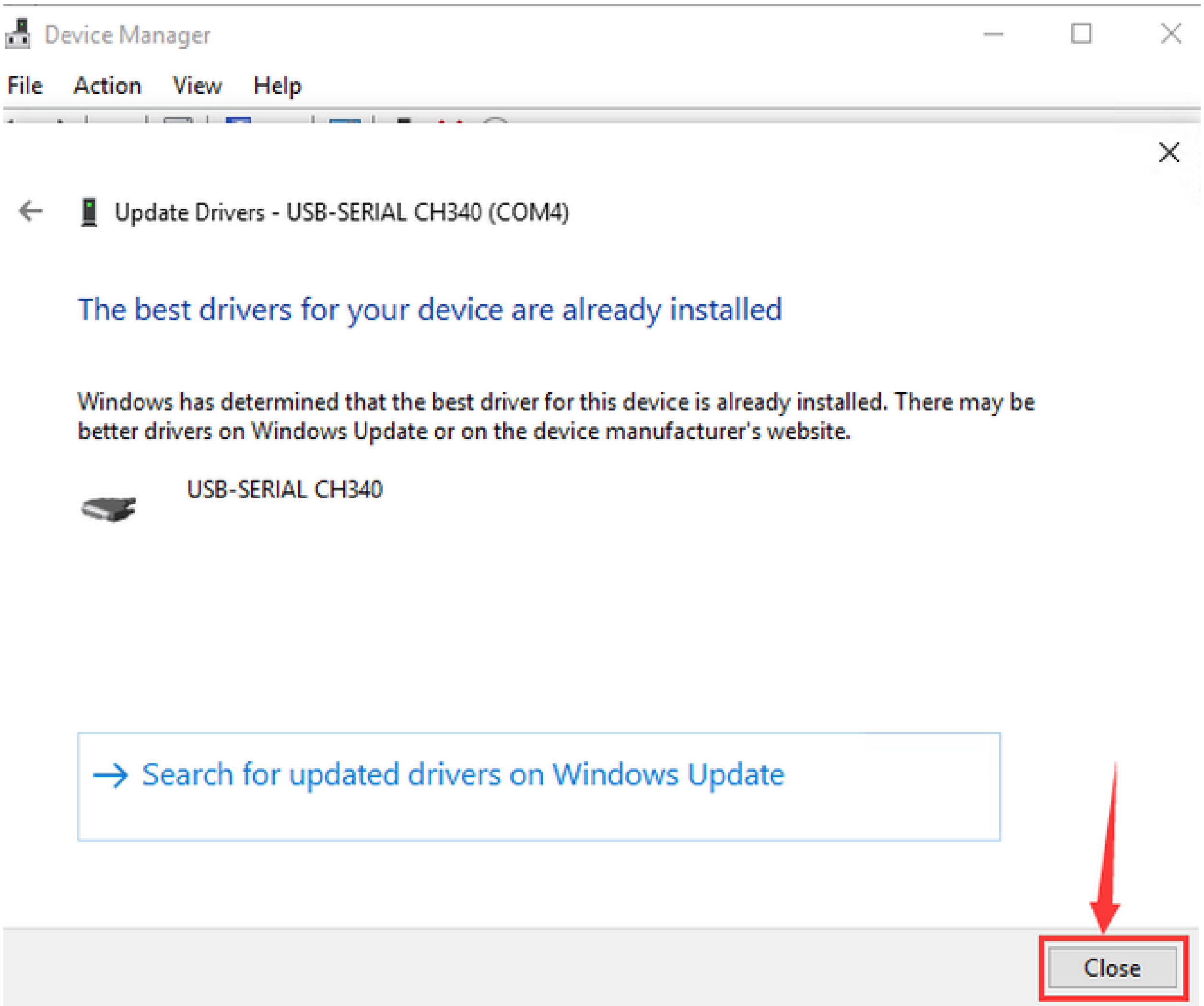


Find the folder usb_ch341_3.1.2009.06 in your computer.

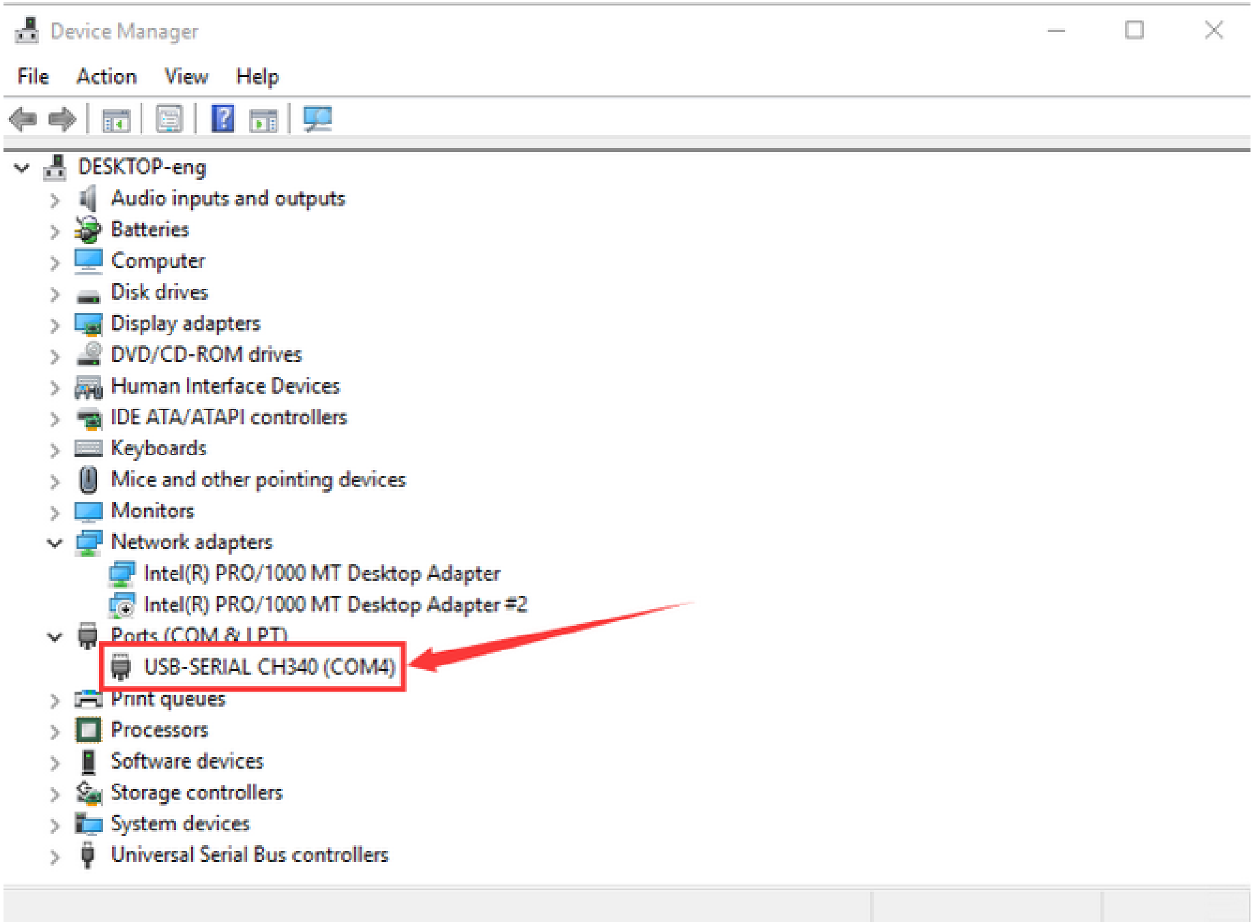


After installation, the following window pop up.

Click Close to select the serial port.



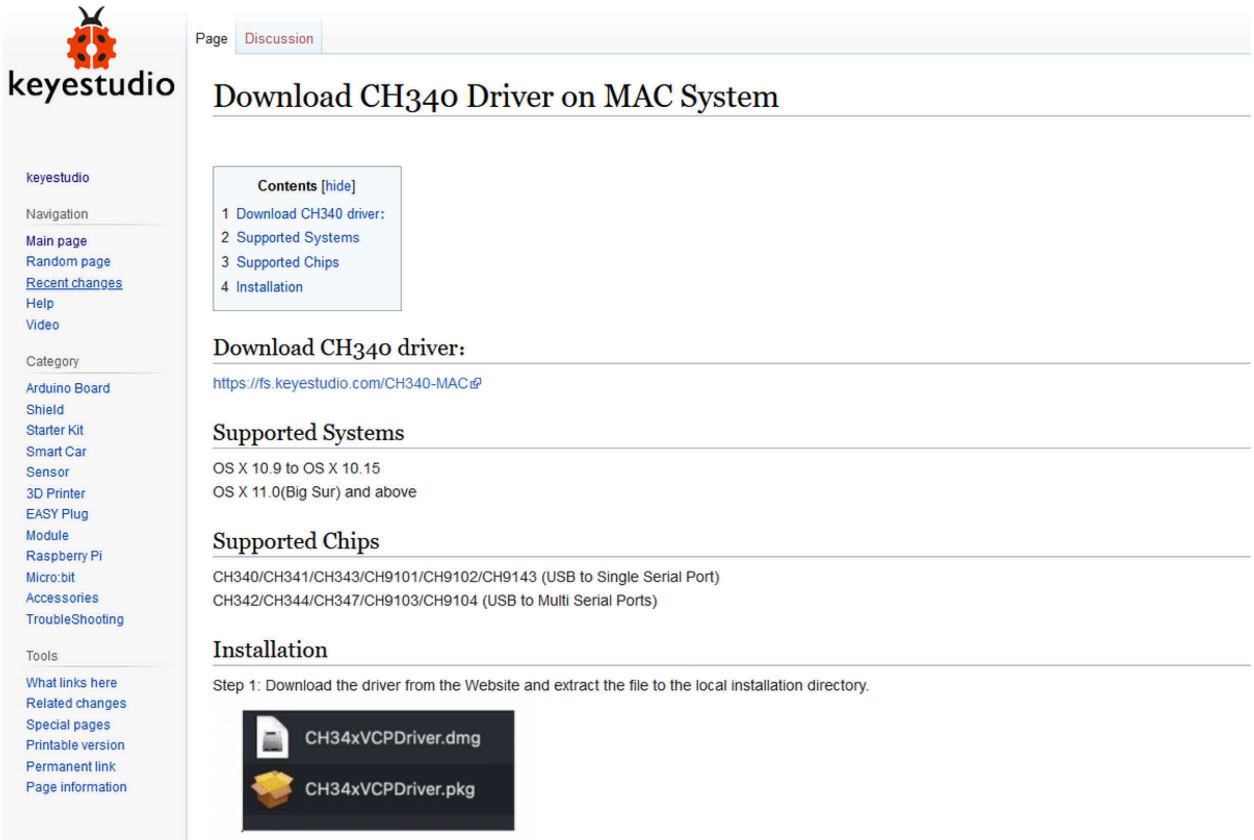
Click Computer–Properties–Device Manager to select PORT:



Detailed Usage for MAC System

Please refer to the following link:

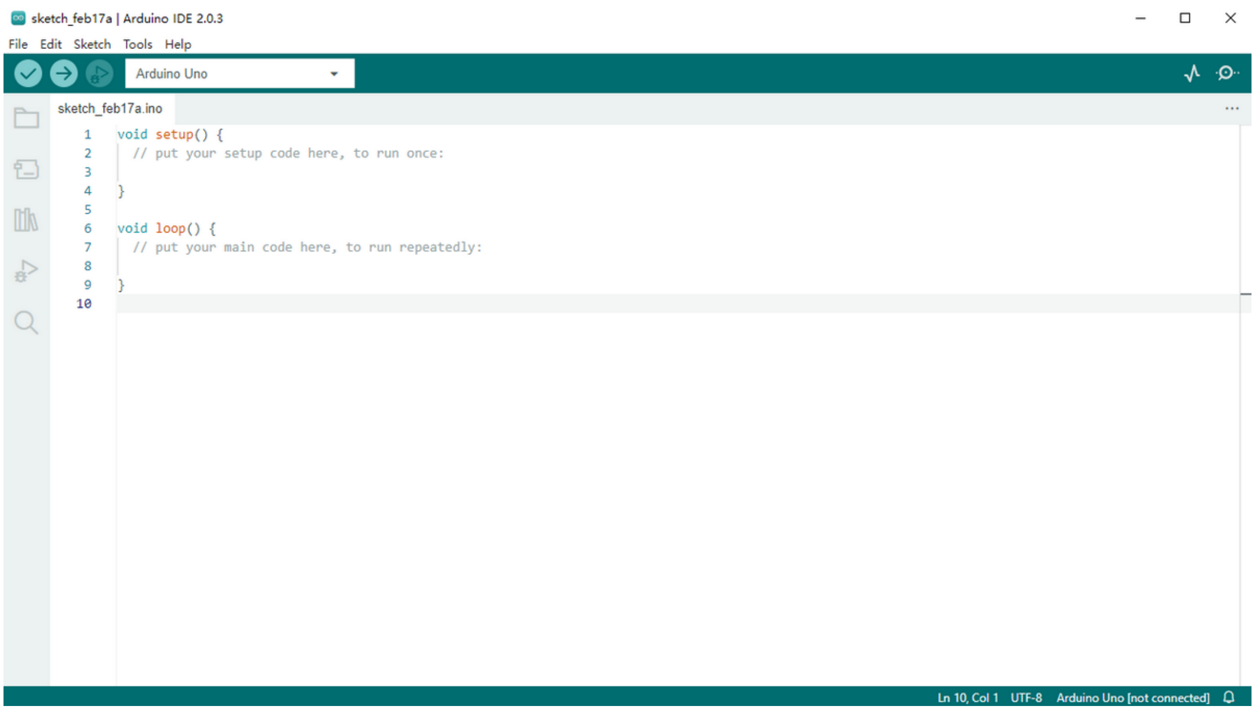
https://wiki.keyestudio.com/Download_CH340_Driver_on_MAC_System



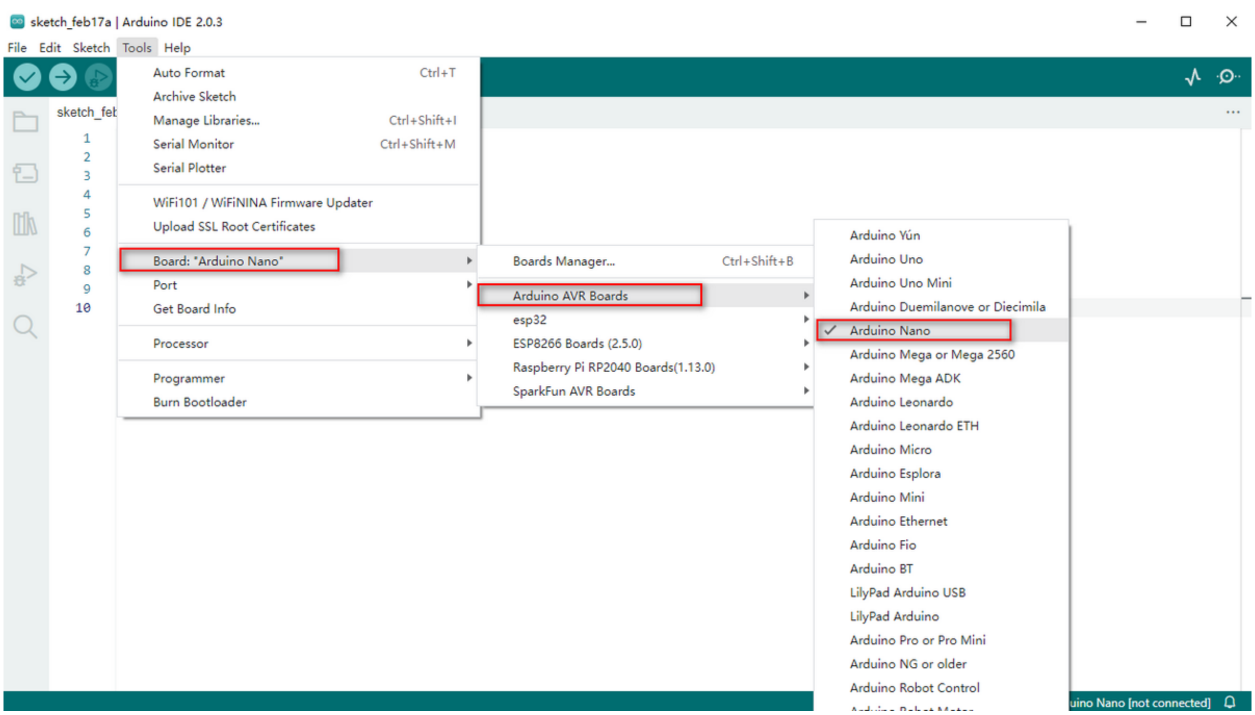
6.1.5 Arduino IDE Settings and Toolbar

Detailed Usage for Windows System

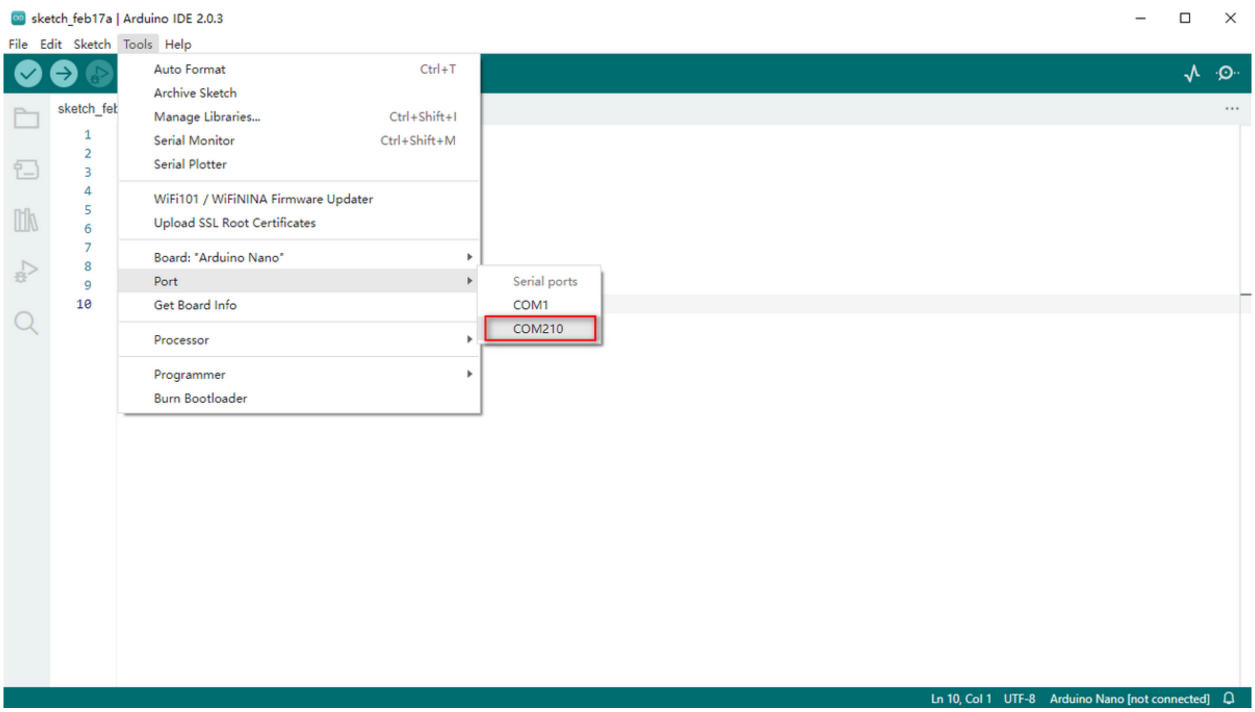
Open Arduino IDE.



Click Tools to select Arduino NANO Board.

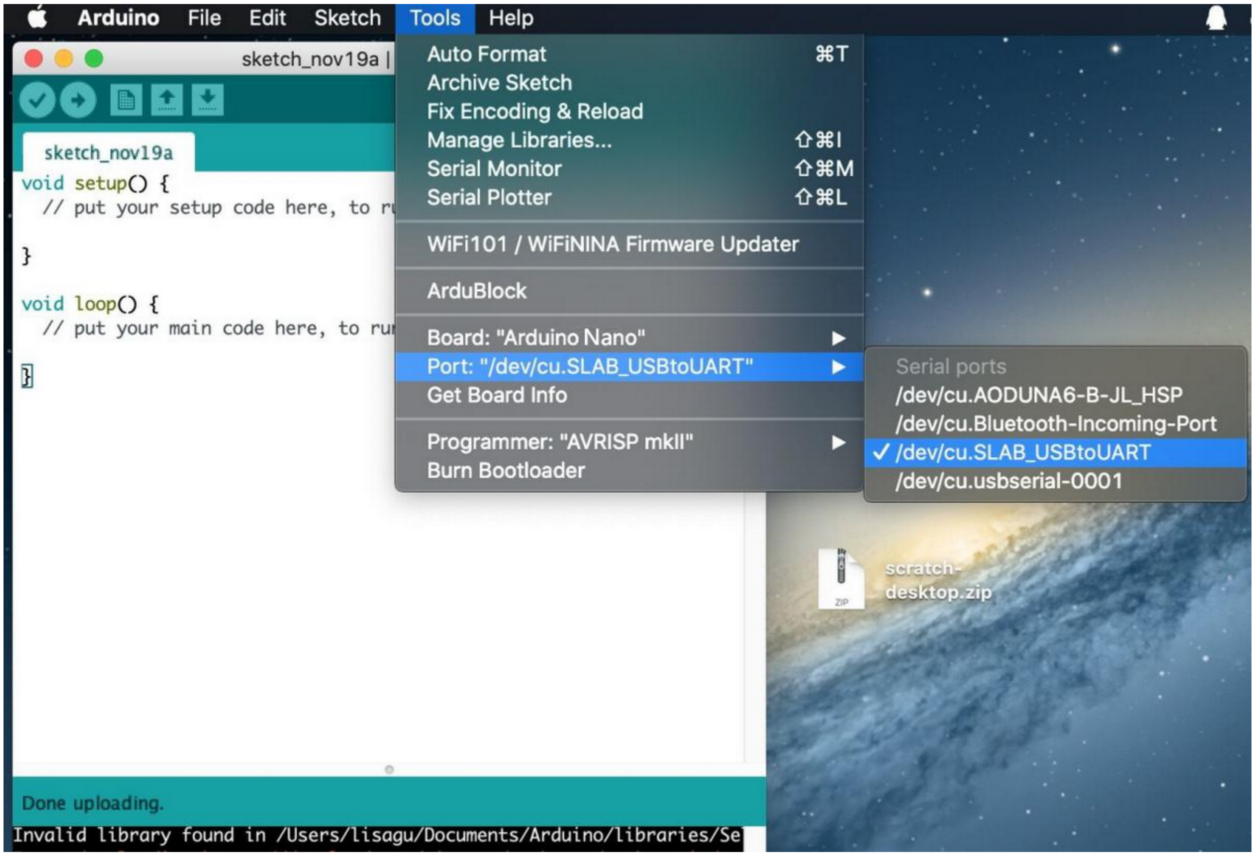


Select the correct COM Port.



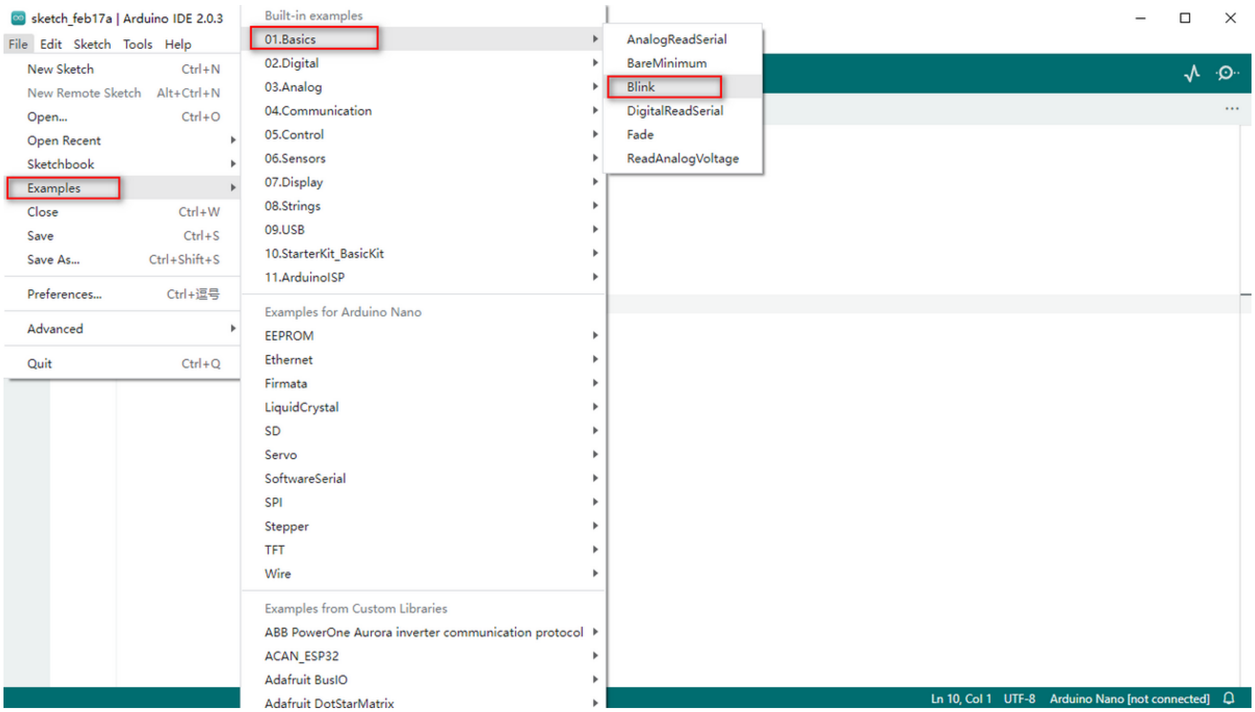
Detailed Usage for MAC System

The setting of Arduino IDE is similar to Chapter 5.1.5.1; The only difference is COM port:

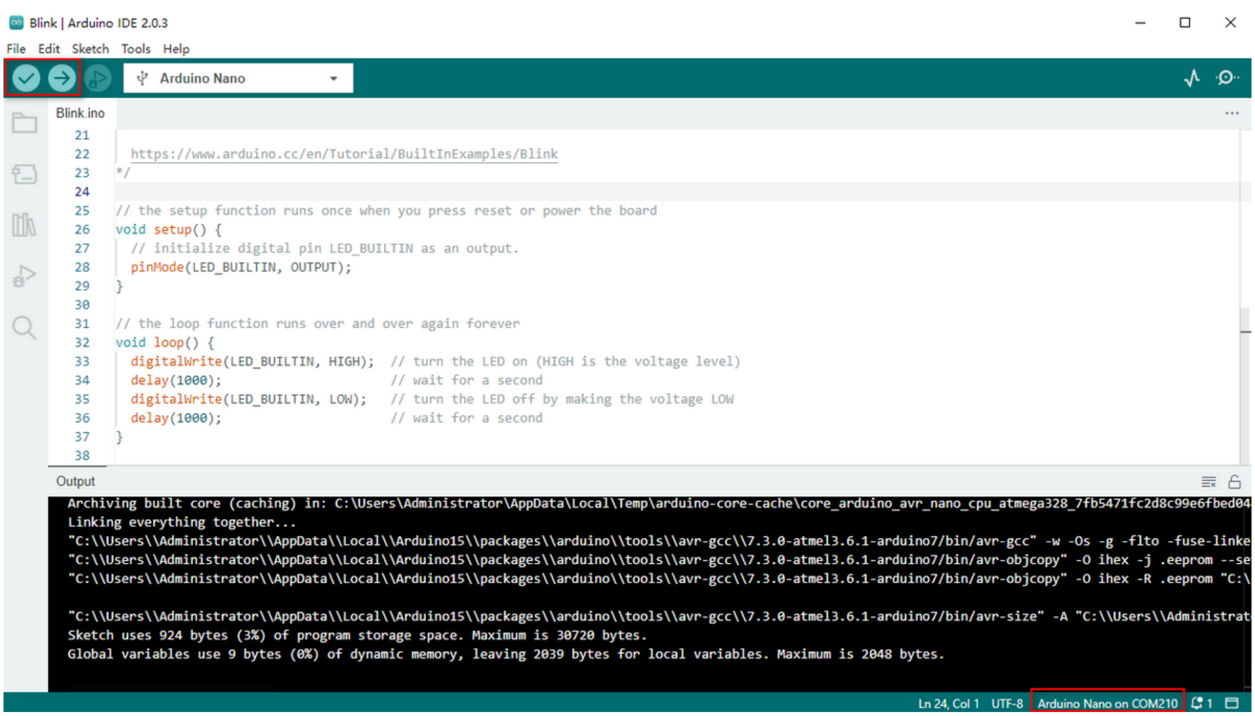


6.1.6 Start Your Program

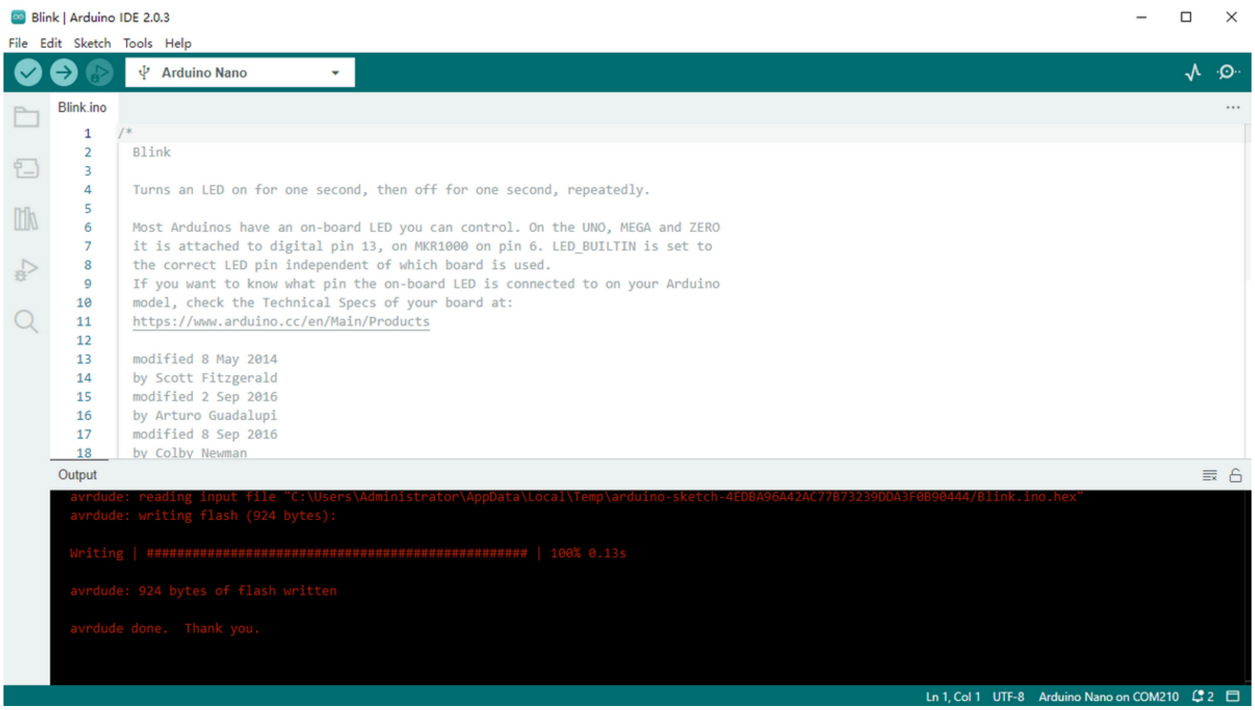
Click File to select Blink in 01.BASIC in the Example code.



Set the board and COM port, and click“”or“→”to compile/examine and upload the code.



The code is successfully uploaded:



The on-board LED will turn on for 1s and off for 1s.

For more details, please refer to: https://www.arduino.cc/reference/en/

6.2 Install Library Files

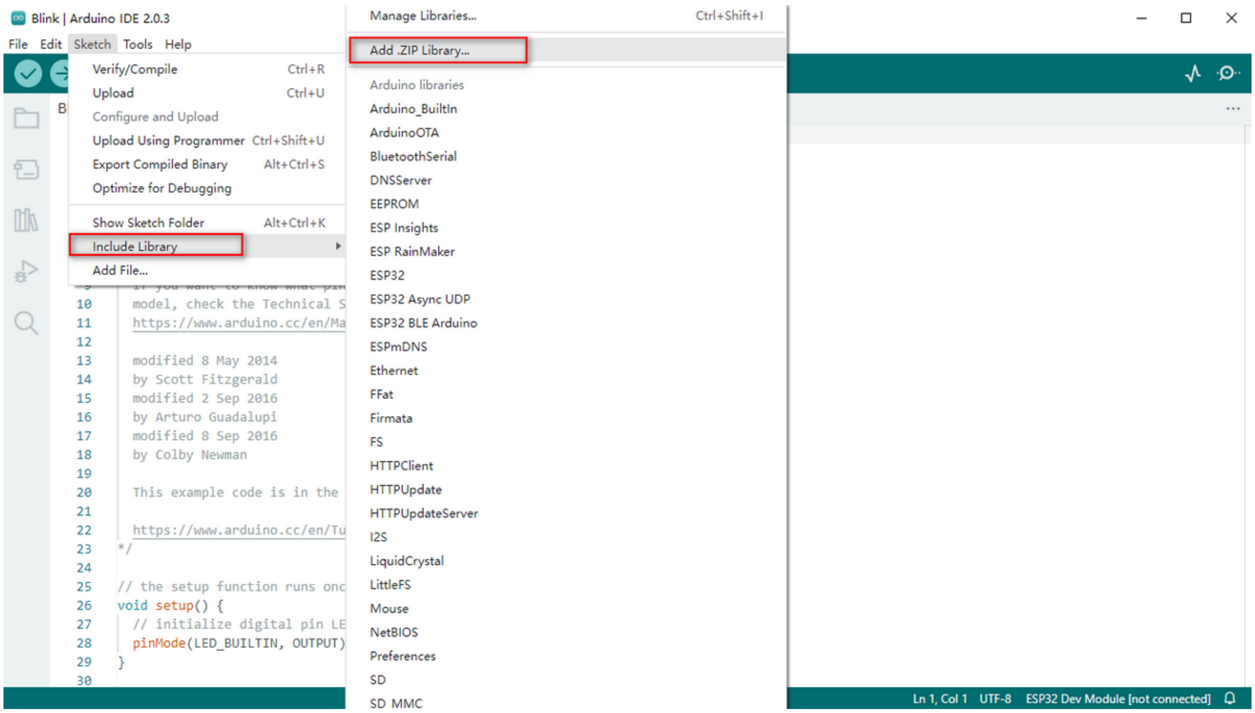
6.2.1 What is an Arduino Library File?

A library is a code collection for easy uploading programs to sensors, displays and modules.

Internet carries hundreds of libraries for download. We have listed built-in libraries and manually-added libraries in reference.

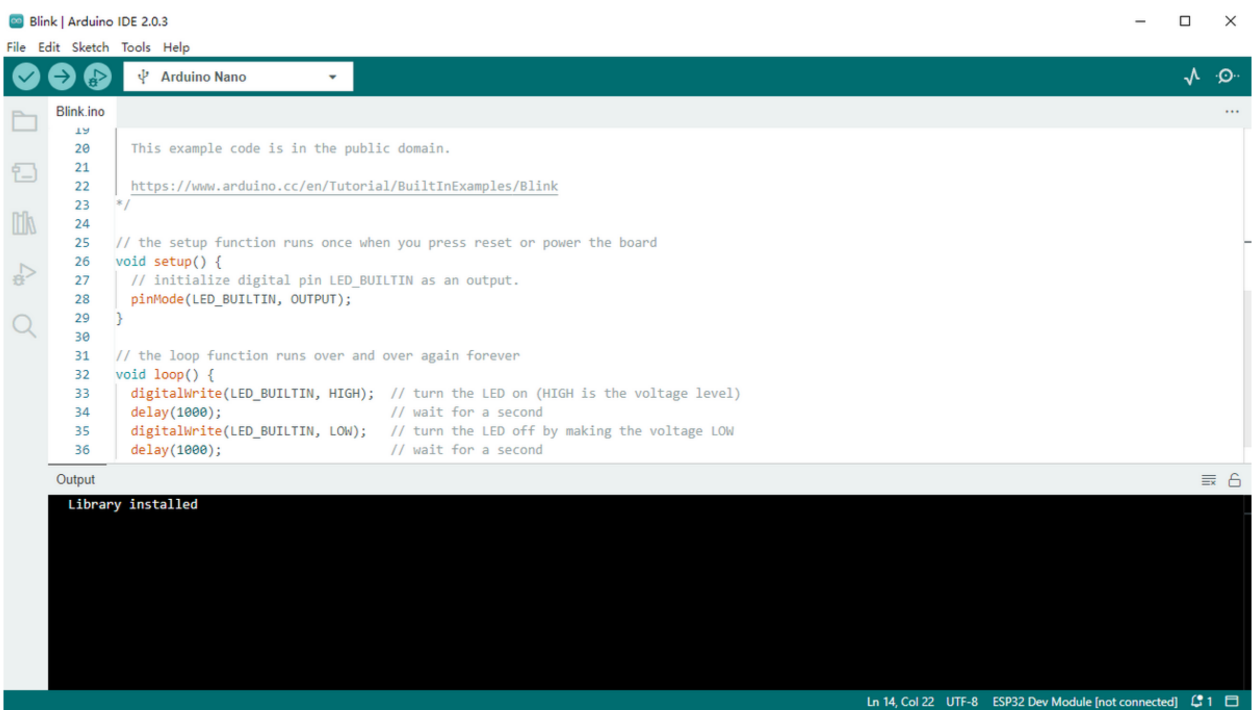
6.2.2 How to Install a Library File?

Click Skerch > Include Library > Add .Zip Library…



Select and click the library file(zip. format) you need to add as library.

The massage bar will display "Library installed" if the file is successfully upload.



For more details, please visit our official website:

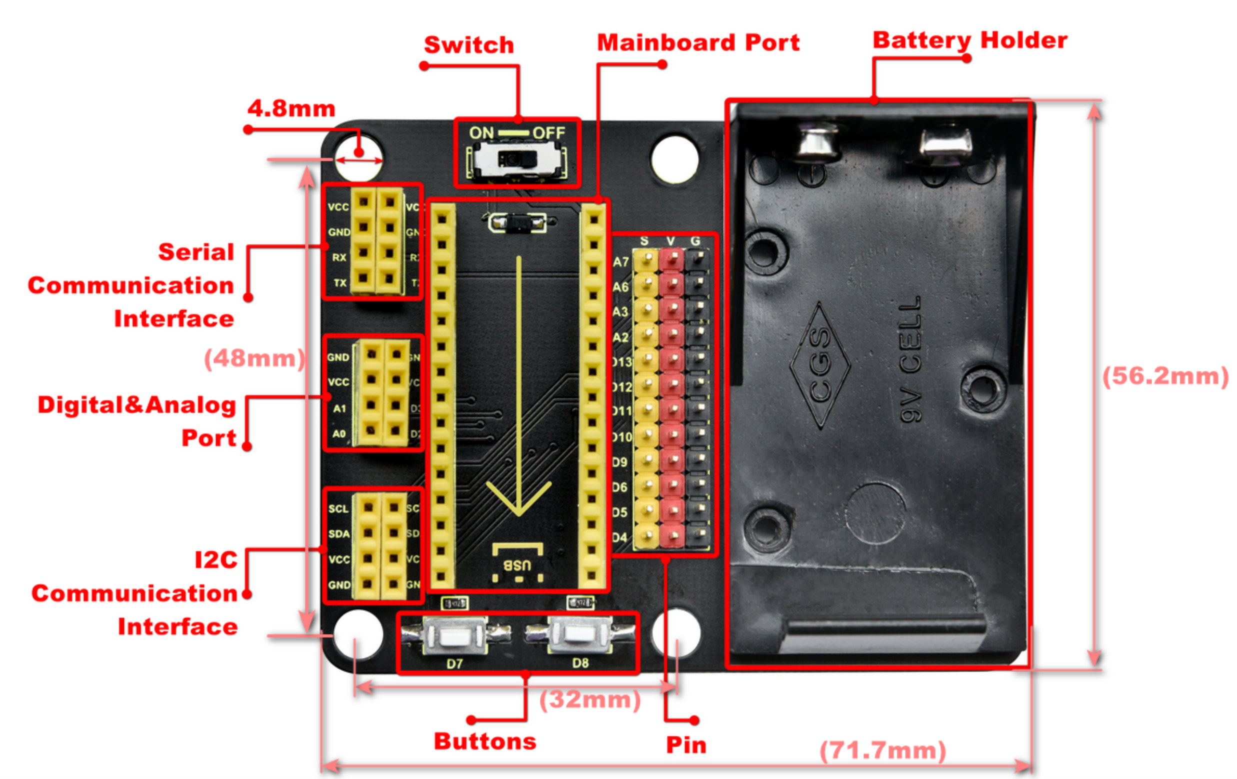
https://www.keyestudio.com/

6.3 Glove Expansion Board

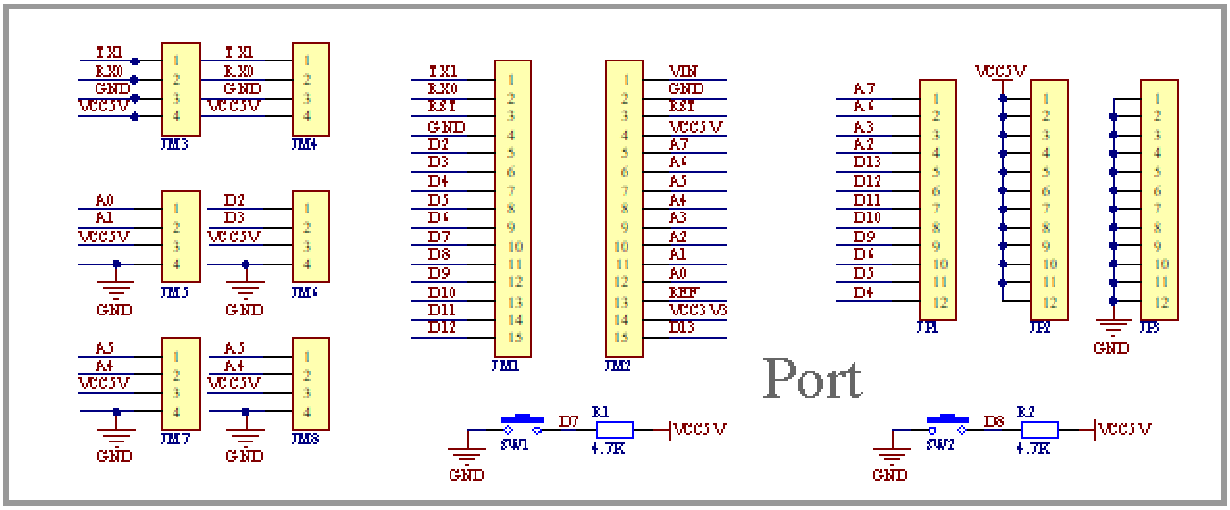
This motion sensing glove expansion board can power independently due to its 9V battery holder.

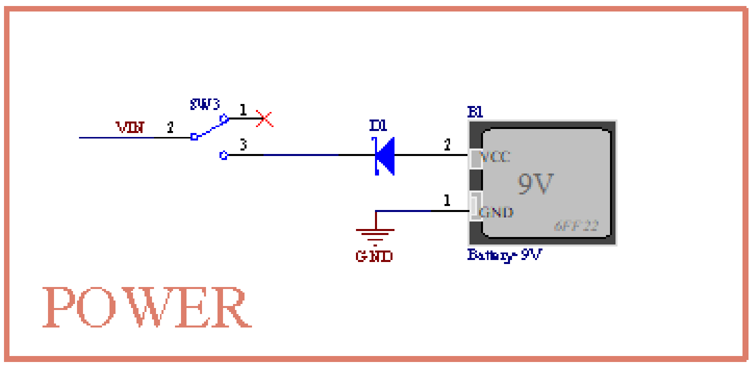
It is equipped with UART and I2C communication interfaces as well as two buttons (D7 and D8), and it is able to connect to external sensors.

What's more, you only need to assemble MPU6050 module and BT24 on the board to complete the installation.



Working principle diagram:





6.4 MPU6050 Basic Information

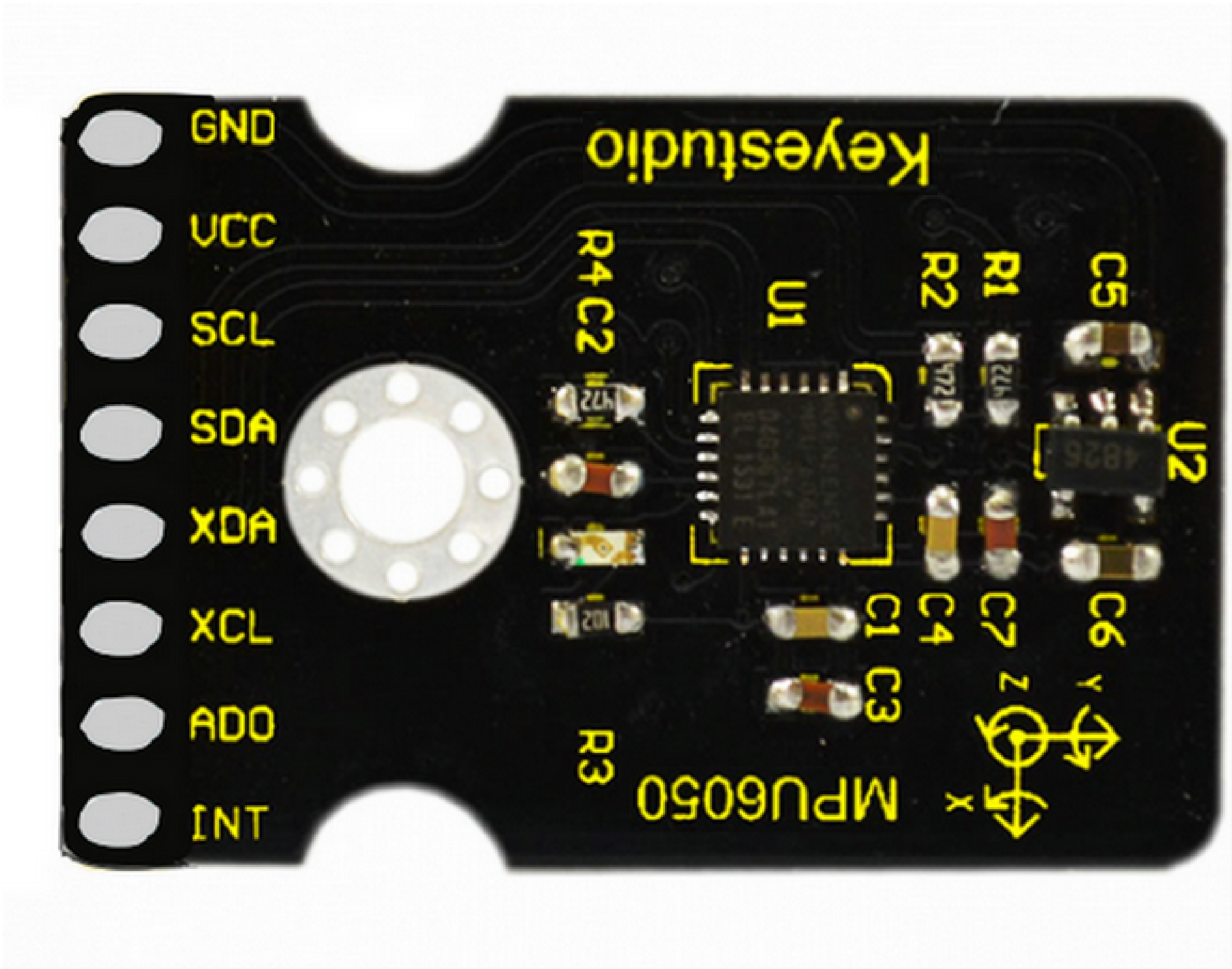
6.4.1 MPU6050

MPU6050 is a 6-axis motion processor(one 3-axis gyroscope and one 3-axis accelerometer). The two sensors are integrated on one chip which can detect static and dynamic motion states, including angular velocity, angle and acceleration.

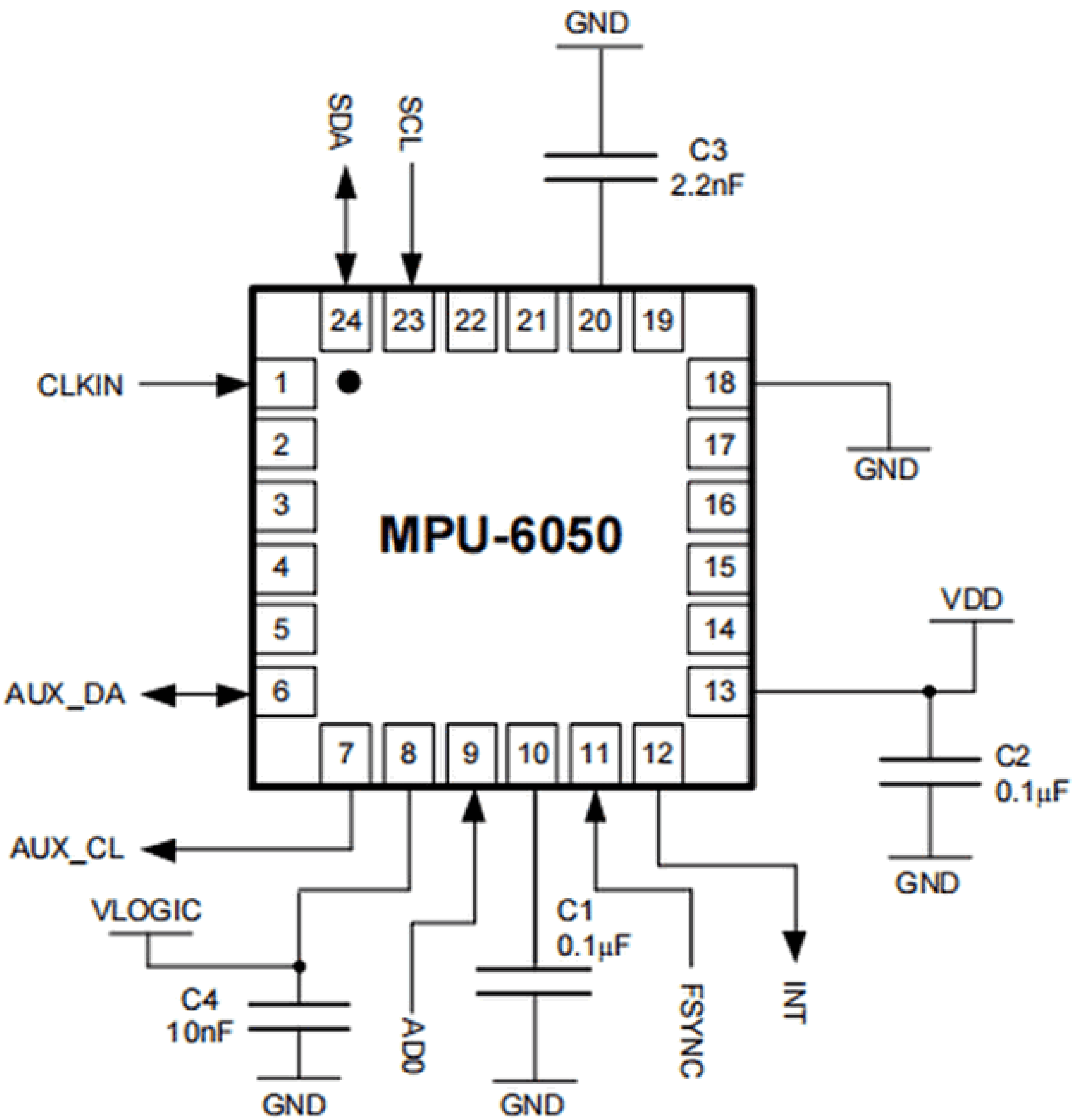
This module is equipped with a 16-pin ADC, which simultaneously reads 6-axis data. Thus, the angular speed, angular angle and the acceleration of the object can be measured.

It also contains a temperature sensor to detect and monitor the temperature of the chip when operating.

Furthermore, it incorporates an DMP (Digital Motion Processor) to acquire the state of object from original data of gyroscope and accelerometer.



Circuit diagram:



NO.	Name	Description
1	GND	Negative pole interface (0V)
2	VCC	Positive pole interface (compatible with 3.3V and 5V)
3	SDA	I2C Data Line. It connects to MCU to transmit data.
4	SCL	I2C Clock Line. It connects to MCU to synchronize data transmission.
5	XDA	I2C Data Line. It connects to external sensors to transmit data.
6	XCL	I2C Clock Line. It connects to external sensors to synchronize data transmission.
7	AD0	I2C sub-address. The address is 0x69 when the board is at a high level, while the address is 0x68 when at low.
8	INT	An external interrupt pin. It detects MPU6050 internal interrupt time.

- Operating voltage: 3.3V, 5V

- Static current: 5A
- Rotating current: 3mA
- Maximum rotation speed: 2000°/s
- Acceleration scales: ±2g, ±4g, ±8g, ±16g
- Temperature range: −10°C ~ +65°C

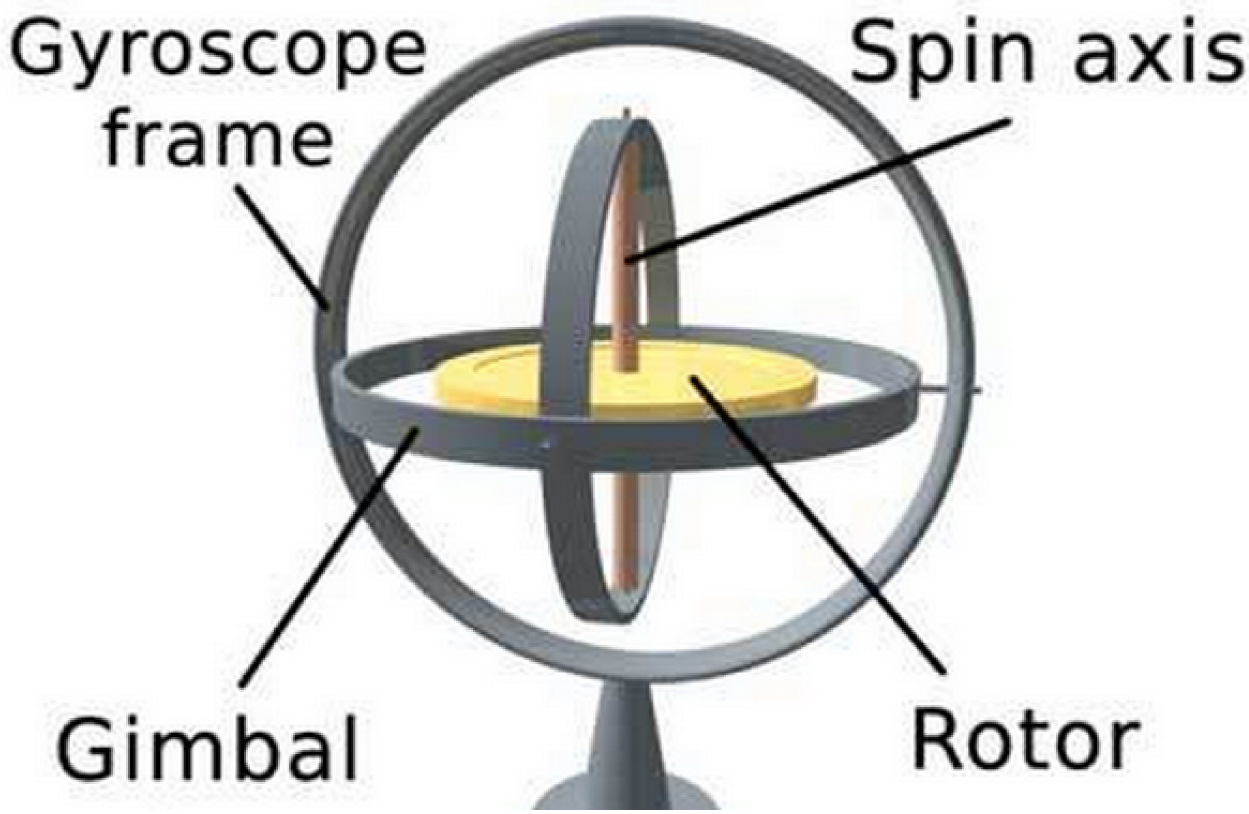
For detailed parameters, please refer to the data sheet.

6.4.2 Gyroscope

A gyroscope, also called rotating angular ratemeter, is a device used to measure rotation speed.

Generally, a gyroscope consists of a magnetoresistor (measuring the gyroscopic force), amplifying and adjusting circuits, and an output circuit.

The gyroscope accurately measures the rotation speed to get precise information. Virtually, it is usually applied in vehicle driving direction detection, aircraft attitude angle measurement as well as precision instrument control systems.



6.4.3 Accelerometer

An accelerometer measures the acceleration of gravity to calculate the tilt angle of a device relative to the horizon and to deduce the movement way of the device.

It also allows robots to know their surroundings and attitudes, and is even utilized to analyze engine vibration.

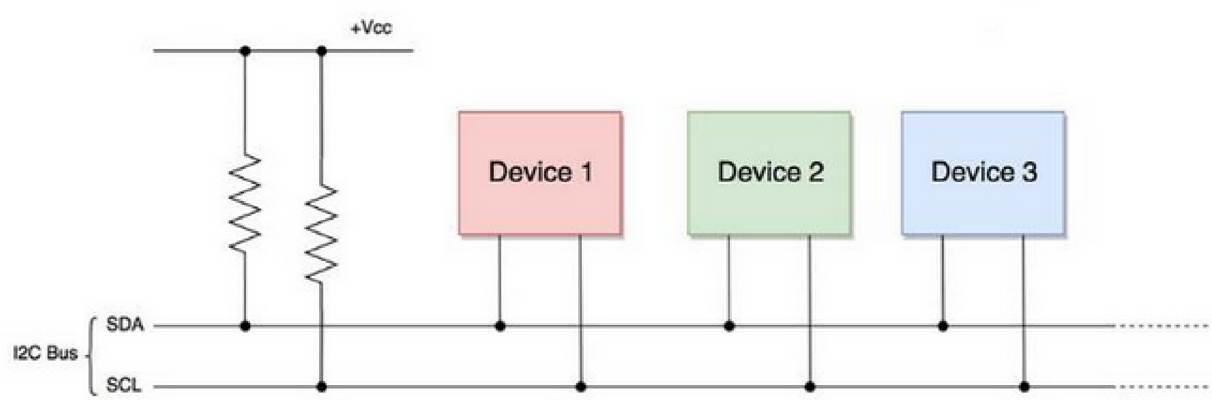
MPU6050adopts gyroscope to measure angles and uses accelerometer to measure the acceleration.

6.4.4 Acquire Data

MPU-6050 boasts I2C serial communication protocol to acquire data.

I2C(Inter-Integrated Circuit, or IIC) is also called two-wire system or TWI (Two-Wire Interface), which is a two-wire bus communication protocol in a host-subordinate model.

The biggest advantage of I2C is that it transmits data only by two wires. In addition, its bus connects 127 nodes in parallel for multiple host devices, and slave devices generally do not need an external power supply as the bus transfers power to them.



Please pay attention that, the host device manipulates clock signals and data transmission, while the slave ones only receives.

I2C bus is composed of SCL (Serial Clock takes charge of the clock signal) and SDA (Serial Data controls data transmission), and it uses an 8-digit transmission mode. Usually, a byte contains nine clock signals, eight of which transmit data and the last one indicates the end of transmission.

Meanwhile, the bus supports multiple bytes transmission by repeating the previous process.

Basic parts of I2C protocol:

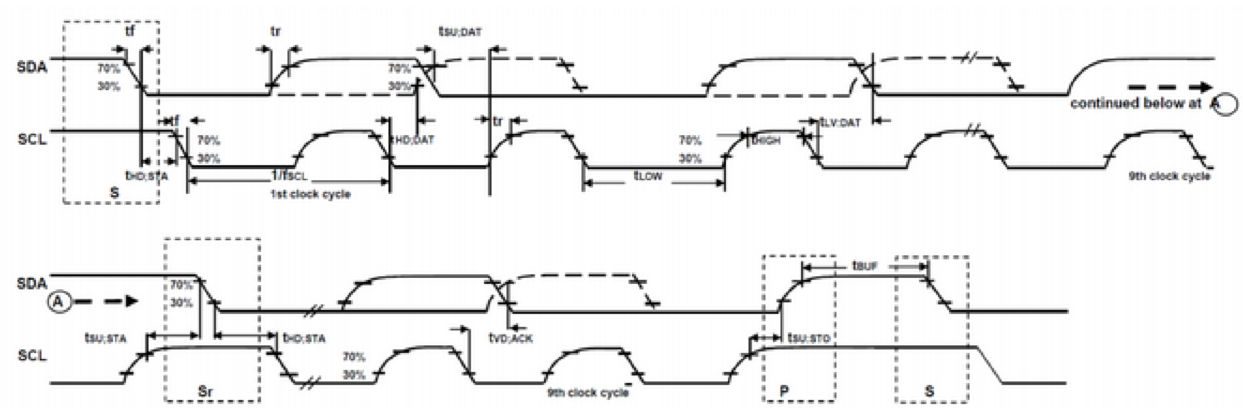
- Starting signal: Before sending data, the sender transmits a starting signal to inform the receiver to prepare for receiving.
- Address code: It tells the receiver that to whom the data is to be sent.
- Data: It is transmitted through one byte each time.
- Stopping signal: The sender ends the data in a stopping signal to note the receiver to prepare for stopping receive.

Serial Port Protocol Timing:

For more details, please refer to : https://www.nxp.com/

Parameters	Conditions	Min	Typical	Max	Units	Notes
I^2C TIMING	**I^2C FAST-MODE**					
f_{SCL}, SCL Clock Frequency				400	kHz	
$t_{HD.STA}$, (Repeated) START Condition Hold Time		0.6			μs	
t_{LOW}, SCL Low Period		1.3			μs	
t_{HIGH}, SCL High Period		0.6			μs	
$t_{SU.STA}$, Repeated START Condition Setup Time		0.6			μs	
$t_{HD.DAT}$, SDA Data Hold Time		0			μs	
$t_{SU.DAT}$, SDA Data Setup Time		100			ns	
t_r, SDA and SCL Rise Time	C_b bus cap. from 10 to 400pF	$20+0.1C_b$		300	ns	
t_f, SDA and SCL Fall Time	C_b bus cap. from 10 to 400pF	$20+0.1C_b$		300	ns	
$t_{SU.STO}$, STOP Condition Setup Time		0.6			μs	
t_{BUF}, Bus Free Time Between STOP and START Condition		1.3			μs	
C_b, Capacitive Load for each Bus Line			< 400		pF	
$t_{VD.DAT}$, Data Valid Time				0.9	μs	
$t_{VD.ACK}$, Data Valid Acknowledge Time				0.9	μs	

Note: Timing Characteristics apply to both Primary and Auxiliary I^2C Bus



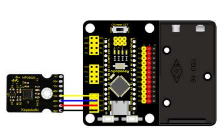
I^2C Bus Timing Diagram

Arduino provides an I2C protocol collection named as Wire.h, so you can directly call its functions to realize I2C and I2C/TWI devices communication.

For detailed introduction, please refer to: https://www.arduino.cc/reference/en/language/functions/communication/wire/

6.4.5 Wiring

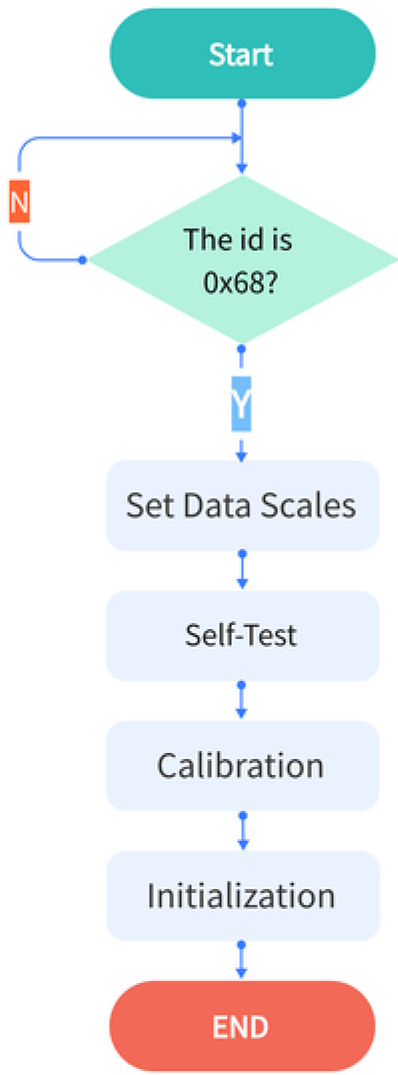
Connect Arduino NANO mainboard and MPU6050 to the expansion board.



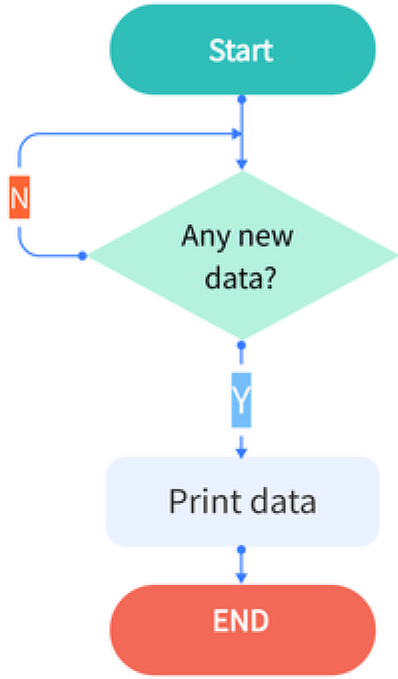
Connect Arduino NANO to your computer via a USB cable and open Arduino IDE.

6.4.6 Data Acquiring Process

Flow chart 1



Flow chart 2



Acquire Sensor ID

Obtain the internal ID of MPU6050 and compare it with the counterpart in the data sheet (0x68).

**Code:*

```
//Acquire the ID value of MPU6050 sensor

uint8_t c = mpu.readByte(MPU6050_ADDRESS, WHO_AM_I_MPU6050);
```

Set Data Scales

Set the scales of gyroscope and accelerometer. Refer to the register sheet and we know:

Resolution of Accelerometer:

AFS_SEL	Full Scale Range	LSB Sensitivity
0	±2*g*	16384 LSB/*g*
1	±4*g*	8192 LSB/*g*
2	±8*g*	4096 LSB/*g*
3	±16*g*	2048 LSB/*g*

Resolution of Gyroscope:

FS_SEL	Full Scale Range	LSB Sensitivity
0	± 250 °/s	131 LSB/°/s
1	± 500 °/s	65.5 LSB/°/s
2	± 1000 °/s	32.8 LSB/°/s
3	± 2000 °/s	16.4 LSB/°/s

Code:

```
//scales are as followings:
// GFS_250DPS:250 DPS (0x00), GFS_500DPS:500 DPS (0x01)
// GFS_1000DPS:1000 DPS (0x10), GFS_2000DPS:2000 DPS (0x11)
// AFS_2G:2 Gs (0x00), AFS_4G: 4 Gs (0x01)
// AFS_8G:8 Gs (0x10), AFS_16G:16 Gs  (0x11)
//Set the scales of MPU6050 sensor.

mpu.settings(AFS_2G, GFS_250DPS);
```

Self-Test

Upload the self-test code to ensure the accurate data and effective output.

Code:

```
//[use in step()] MPU6050 inspects itself and stores 3-axis data of accelerometer  and gyroscope in SelfTest[6].

//Set the scales of acceleration to 8g and scales of gyroscope to 250dps when they are in their self-test.

// Self-test value storing container

float SelfTest[6];

// MPU6050 conducts a self-test

mpu.MPU6050SelfTest(SelfTest);
```

Calibration

Upload the calibration code.

Readings are impacted by temperature, humidity, vibration and external magnetic field. Thus, a calibration process guarantees the accuracy.

Code:

```
//[Use in step()] calibrate accelerometer  and gyroscope, and load biases in the bias register and store the values in gyroBias[3] and accelBias[3].

float gyroBias[3] = {0, 0, 0}; // Correct gyroscope and accelerometer  bias.

float accelBias[3] = {0, 0, 0};


mpu.calibrateMPU6050(gyroBias, accelBias);
```

Initialization

Initialize the device.

Cut off the interrupt interface and AUX IIC interface, ban FIFO, and set the gyroscope sampling rate and the DLPF.

This step can calibrate the sensor to make sure a normal state.

Code:

```
//[use in step()] initialize MPU6050

mpu.initMPU6050();
```

Data Preparation

Check whether data are prepared for collection.

Code:

```
//Determine whether data are prepared

if(mpu.readByte(MPU6050_ADDRESS, INT_STATUS) & 0x01)
{
}
```

Read Sensor Data

Read the value of the accelerometer, gyroscope and temperature sensor.

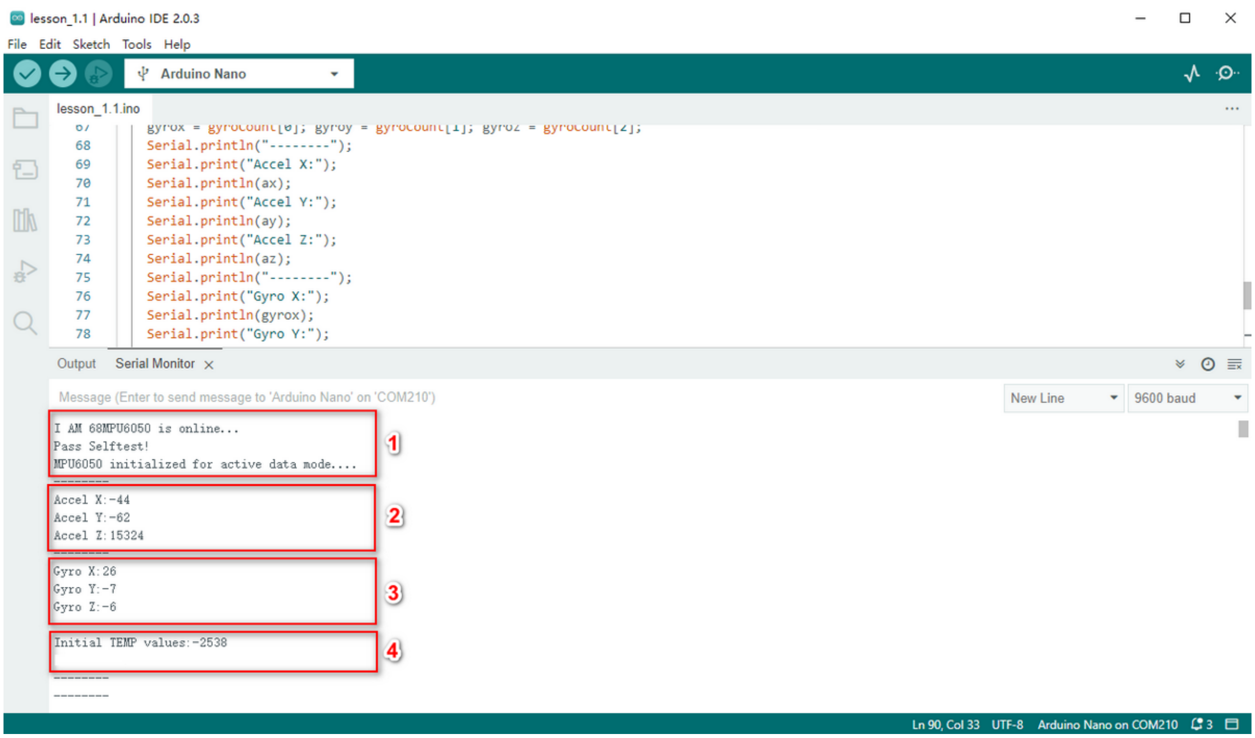
Code:

```
//Read the initial value of accelerometer, gyroscope and temperature senor

int16_t accelCount[3];      // Store 16-bit signed output of accelerometer

int16_t gyroCount[3];      // Store 16-bit signed output of gyroscope

int16_t tempCount;        // Store the real internal chip temperature in degrees Celsius



// Read the initial value of accelerometer

mpu.readAccelData(accelCount);

// Read the initial value of gyroscope

mpu.readGyroData(gyroCount);

//Read the initial value of temperature sensor

tempCount = mpu.readTempData();
```

6.4.7 Test Results

Place the expansion board smoothly, press and hold the reset button. The more balanced the MPU6050 is, the more accurate the data it acquired will be.

Open Arduino IDE serial monitor, and you will see that the angular speed, gyroscope data and temperature refresh per 0.5s.



1. The initialization of MPU6050 will spend about 3s. Initialize it once only. Please put the expansion board and MPU6050 smoothly in initialization.
2. Initial acceleration value of MPU6050.
3. Initial gyroscope value of MPU6050.
4. Initial temperature value of MPU6050.

6.4.8 Test Code

Please refer to the folder lesson_1_1.

[lesson_1_1.ino]:

```
#include <MPU6050.h>

MPU6050lib mpu;

int16_t accelCount[3];      // Store 16-bit signed output of accelerometer

int16_t gyroCount[3];      // Store 16-bit signed output of gyroscope

int16_t tempCount;        // Store the real internal chip temperature in degrees Celsius

float gyroBias[3] = {0, 0, 0}; // Correct gyroscope and accelerometer  bias

float accelBias[3] = {0, 0, 0};
```

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```
float SelfTest[6];        // Self-test value storing container


void setup()

{

 Wire.begin();

 Serial.begin(9600);

 // Read the WHO_AM_I register, this is a good test of communication

 // Read WHO_AM_I register for MPU-6050

 uint8_t c = mpu.readByte(MPU6050_ADDRESS, WHO_AM_I_MPU6050);

 Serial.print("I AM ");

 Serial.print(c, HEX);

 //Set the minimum scale if the device is in self-test

   // Possible gyro scales (and their register bit settings) are:

   // 250 DPS (0x00), 500 DPS (0x01), 1000 DPS (0x10), and 2000 DPS  (0x11).

   // Possible accelerometer scales (and their register bit settings) are:

   // 2 Gs (0x00), 4 Gs (0x01), 8 Gs (0x10), and 16 Gs  (0x11).

 mpu.settings(AFS_8G, GFS_250DPS);

 // version WHO_AM_I should always be 0x68 //MPU6050 address 1: 0x68, address 2: 0x98

 if (c == 0x68 || c == 0x98) {

  Serial.println("MPU6050 is online...");

  // Start by performing self test

  mpu.MPU6050SelfTest(SelfTest);


  if (SelfTest[0] < 1.0f && SelfTest[1] < 1.0f && SelfTest[2] < 1.0f && SelfTest[3] < 1.
↪0f && SelfTest[4] < 1.0f

  && SelfTest[5] < 1.0f) {

   Serial.println("Pass Selftest!");

   // Calibrate gyro and accelerometers, load biases in bias registers
```

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```
   mpu.calibrateMPU6050(gyroBias, accelBias);

   mpu.settings(AFS_2G, GFS_250DPS);

   mpu.initMPU6050();

   // Initialize device for active mode read of accelerometer , gyroscope, and␣
↪temperature

   Serial.println("MPU6050 initialized for active data mode....");

  }

  else{

   Serial.print("Could not connect to MPU6050: 0x");

   Serial.println(c, HEX);

   // Loop forever if communication doesn't happen

   while (1) ;

  }

 }

}

void loop()

{

 // If data ready bit set, all data registers have new data

 // check if data ready interrupt

 if (mpu.readByte(MPU6050_ADDRESS, INT_STATUS) & 0x01) {

  // Read the x/y/z adc values

  mpu.readAccelData(accelCount);

  // Read the x/y/z adc values

  mpu.readGyroData(gyroCount);

  Serial.println("--------");

  Serial.print("Accel X:");
```

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```
  Serial.println(accelCount[0]);

  Serial.print("Accel Y:");

  Serial.println(accelCount[1]);

  Serial.print("Accel Z:");

  Serial.println(accelCount[2]);

  Serial.println("--------");

  Serial.print("Gyro X:");

  Serial.println(gyroCount[0]);

  Serial.print("Gyro Y:");

  Serial.println(gyroCount[1]);

  Serial.print("Gyro Z:");

  Serial.println(gyroCount[2]);

  Serial.println("--------");

  // Read the x/y/z adc values

  tempCount = mpu.readTempData();

  // Temperature in degrees Centigrade

  Serial.print("Initial TEMP values:");

  Serial.println(tempCount);

  Serial.println("--------");

  delay(500);

}
```

6.4.9 Expansion Code

The initial temperature value of MPU6050 cannot be applied in our daily use, hence it needs to be converted to the usual unit.

Conversion Formula:

$$Temperature in degrees C = \frac{TEMPOUT Register Value as a signed quantity}{340} + 36.53$$

For detailed operations, please refer to the data sheet.

Please refer to the folder lesson_1_2.

[lesson_1_2.ino]:

```
#include <MPU6050.h>



MPU6050lib mpu;



int16_t tempCount;        // Store the real internal chip temperature in degrees Celsius

float temperature;        // Store the actual temperature in degrees Centigrade

float gyroBias[3] = {0, 0, 0}; // Correct gyroscope and accelerometer  bias

float accelBias[3] = {0, 0, 0};

float SelfTest[6];        // Self-test value storing container



void setup()

{

 Wire.begin();

 Serial.begin(9600);

 // Read the WHO_AM_I register, this is a good test of communication

 // Read WHO_AM_I register for MPU-6050

 uint8_t c = mpu.readByte(MPU6050_ADDRESS, WHO_AM_I_MPU6050);

 Serial.print("I AM ");

 Serial.print(c, HEX);

 //Set the minimum scales if the device is in self-test
```

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```
  // Possible gyro scales (and their register bit settings) are:

  // 250 DPS (0x00), 500 DPS (0x01), 1000 DPS (0x10), and 2000 DPS  (0x11).

  // Possible accelerometer scales (and their register bit settings) are:

  // 2 Gs (0x00), 4 Gs (0x01), 8 Gs (0x10), and 16 Gs  (0x11).

mpu.settings(AFS_8G, GFS_250DPS);

// version WHO_AM_I should always be 0x68 //MPU6050 address 1: 0x68, address 2: 0x98

if (c == 0x68 || c == 0x98) {

 Serial.println("MPU6050 is online...");

 // Start by performing self test

 mpu.MPU6050SelfTest(SelfTest);

 if (SelfTest[0] < 1.0f && SelfTest[1] < 1.0f && SelfTest[2] < 1.0f && SelfTest[3] < 1.
↪0f && SelfTest[4] < 1.0f

 && SelfTest[5] < 1.0f) {

  Serial.println("Pass Selftest!");

  // Calibrate gyro and accelerometers, load biases in bias registers

  mpu.calibrateMPU6050(gyroBias, accelBias);

  mpu.settings(AFS_2G, GFS_250DPS);

  mpu.initMPU6050();

  // Initialize device for active mode read of accelerometer , gyroscope, and␣
↪temperature

  Serial.println("MPU6050 initialized for active data mode....");

 }

 else{

  Serial.print("Could not connect to MPU6050: 0x");

  Serial.println(c, HEX);

  // Loop forever if communication doesn't happen

  while (1) ;
```

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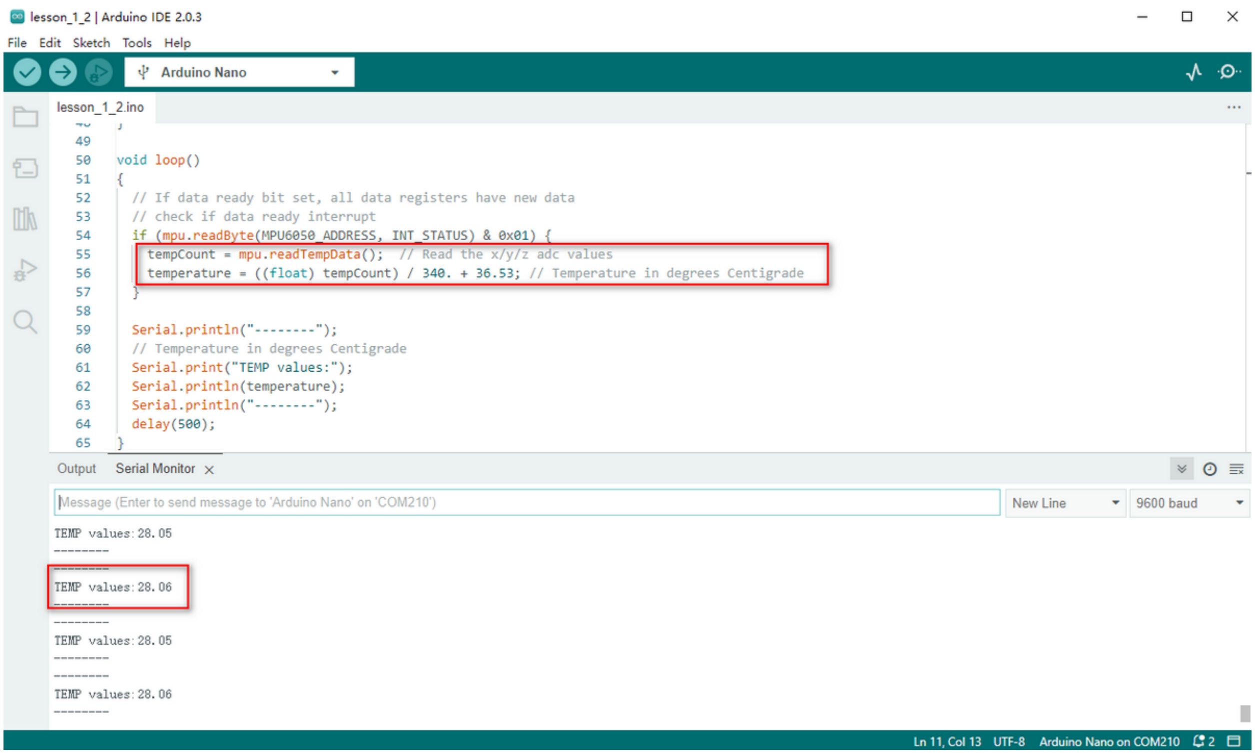
```
  }

 }

}


void loop()

{

 // If data ready bit set, all data registers have new data

 // check if data ready interrupt

 if (mpu.readByte(MPU6050_ADDRESS, INT_STATUS) & 0x01) {

  tempCount = mpu.readTempData(); // Read the x/y/z adc values

  temperature = ((float) tempCount) / 340. + 36.53; // Temperature in degrees Centigrade

 }


 Serial.println("--------");

 // Temperature in degrees Centigrade

 Serial.print("TEMP values:");

 Serial.println(temperature);

 Serial.println("--------");

 delay(500);

}
```

Output the actual temperature value:



6.5 MPU6050 Attitude

Make an Attitude Fusion Solution on the accelerometer and gyroscope data.

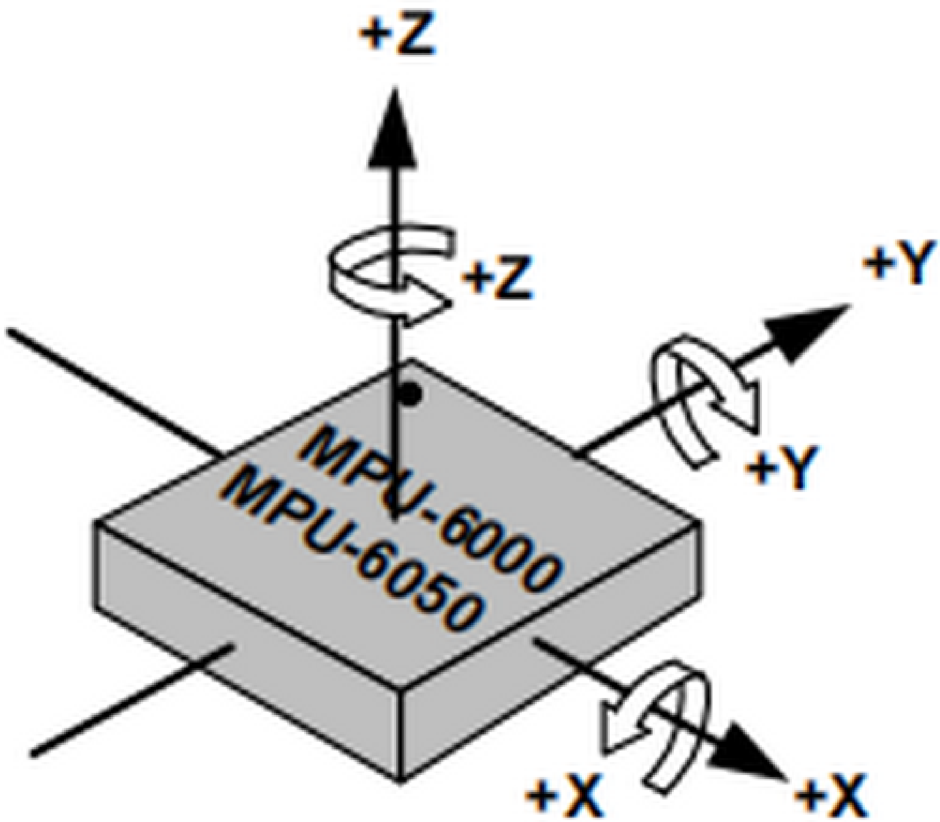
To solve problems of universal joint deadlock of Euler Angles and to simplify calculation, a quaternion (three real numbers and an imaginary number) is adopted to represent the attitude in an Attitude Fusion Solution.

After processing, the quaternion converts into Euler Angle, which gets more precise rotation information to control drones, mobile robots and other devices.

6.5.1 Attitude

MPU6050 measures the attitude of an object in three dimensions: Roll, Pitch and Yaw. It also detects the acceleration to gain the speed and position after calculation.

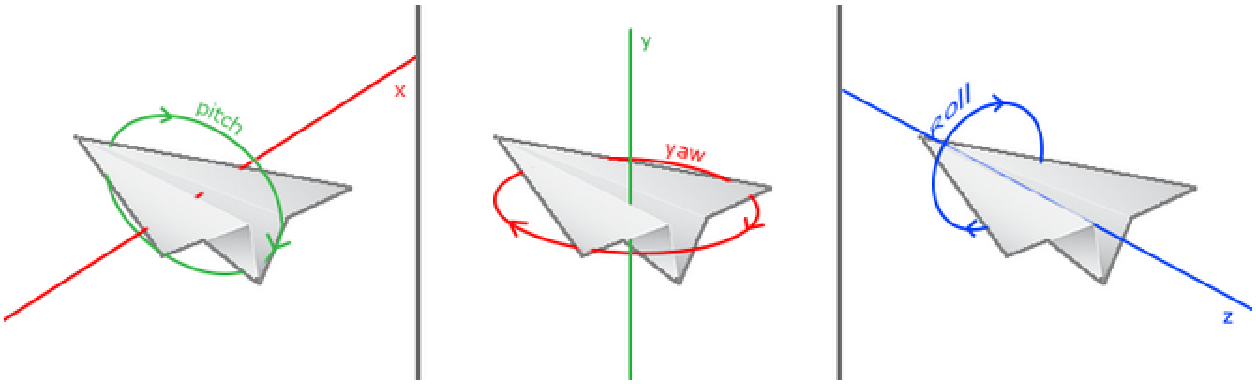
Three-Axis:



An Euler Angle is a rotation angle of an object in three dimensional space whose axis is arbitrarily adjustable.

It includes three angles: Roll Angle, Pitch Angle and Yaw Angle.

Roll Angle	A rotation angle with x-axis as the rotational axis
Pitch Angle	**A rotation angle with y-axis as the rotational axis**
Yaw Angle	**A rotation angle with z-axis as the rotational axis**



When acquiring Yaw Angle, MPU6050 internal gyroscope automatically calibrates and sets its own angle to 0, which will cause a Yaw Angle Null Shift.

A Null shift, which is unavoidable and limited by hardware, is an effect that the detected data occasionally drifts from its null point.

Therefore, we add a magnetometer to calibrate MPU6050.

Hence, in the following tutorials, our main contents are Roll Angle and Pitch Angle.

6.5.2 Acquire Attitude

In a filtering algorithm, errors reduce and 6-axis data are converted into quaternions, which will then convert to Euler Angle to indicate the concrete data of attitude.

Ways to acquire quaternions:

1. Use the built-in DMP. An embedded motion driver library is prepared for outputting attitude solutions quaternions.
2. Use the high-efficiency locating filter of Sebastian Madgwick.

This filter adopts a modelless estimation algorithm to estimate the attitude for inertia/magnetic sensor arrays.

The computational intensity of the quaternion filtering algorithm is much small. This is the reason why it can operate on Arduino Pro Mini development board with a speed of 8MHz.

In the algorithm, the change angle is expressed as a quaternion, and it effectively filters out noises and reduces positioning errors.

Attitude estimation formula:

$$(= qt * qt - 1)$$

$$qt + 1 = qt + (1/)*$$

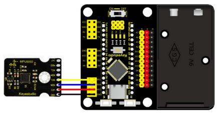
: the difference value of quaternions, which represents the change angle between two quaternons.

qt: the current quaternon (present attitude) qt-1: the last read quaternon (last attitude)

qt+1: the next quaternon (next attitude), which is calculated through the current quaternion and its difference.

: an adjustable parameter, which controls the sensitivity of the filter.

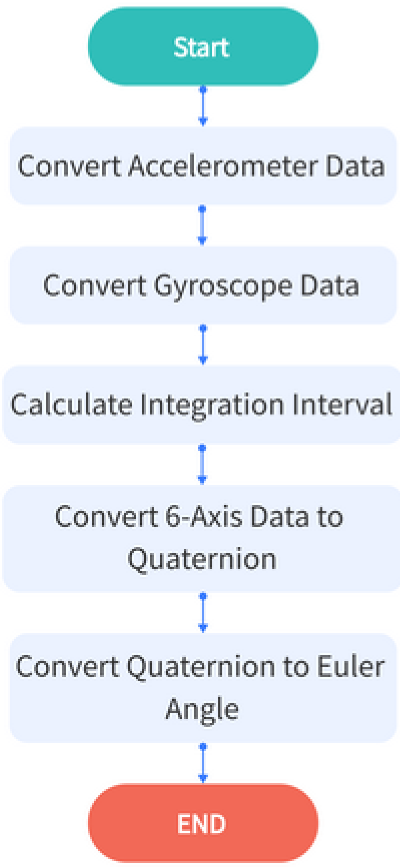
6.5.3 Wiring



Install MPU6050 on the expansion board and connect it to your computer via USB cable.

6.5.4 Attitude Acquiring Process

Flow chart:



Convert Accelerometer Data

Convert the underlying data of accelerometer into the actual data.

Acceleration Calculation Formula:

$$Acceleration = \frac{OriginalAccelerationValue}{DataResolution}(m/s^2)$$

For example, set the scale to ±2g. If the reading of ADC is ±32768ADC value of 1g is +32768/2=16384LSB/g.

Code:

```
mpu.readAccelData(accelCount); //Read the x/y/z adc values

aRes = mpu.getAres();

//Now we'll calculate the accleration value into actual g's

ax = (float)accelCount[0] * aRes; //get actual g value, this depends on scale being set

ay = (float)accelCount[1] * aRes;

az = (float)accelCount[2] * aRes;
```

Convert Gyroscope Data

Convert the underlying data of gyroscope into the actual data.

Angular Speed Calculation Formula:

$$AngularSpeed = \frac{OriginalAngularSpeedValue}{DataResolution}(/s)$$

ADC output range is ±32768. If we set the measuring range to ±2000°/s, and original ADC reading is 300, the data resolution will be 32768/2000=16.384LSB/(°/s), and the angular speed will be 300/16.384=18.3105(°/s).

Code:

```
mpu.readGyroData(gyroCount);    // Read the x/y/z adc values

gRes = mpu.getGres();       //Acquire the converted value



// Calculate the gyro value into actual degrees per second

gyrox = (float)gyroCount[0] * gRes; // get actual gyro value, this depends on scale being set

gyroy = (float)gyroCount[1] * gRes;

gyroz = (float)gyroCount[2] * gRes;
```

Calculate Integration Interval

Acquire the time to calculate the integration interval, and convert it to quaternion .

Code:

```
// Acquire the current time of the system in ms

 Now = micros();

 // set integration time by time elapsed since last filter update

 deltat = ((Now - lastUpdate) / 1000000.0f);

 lastUpdate = Now;

 if(lastUpdate - firstUpdate > 10000000uL) {

  beta = 0.041; // decrease filter gain after stabilized

  zeta = 0.015; // increase gyro bias drift gain after stabilized

 }
```

Convert 6-Axis Data to Quaternion

Convert the accelerometer and gyroscope data into quaternion.

Each axis value needs to be translated into a radian before quaternion conversion.

According to proportional relation,"gyrox * PI / 180.0f"means the conversion of gyrox angle to radian, as radians belong to angular measurement while angles are circular measurement.

Code:

```
// convert gyroscope data to

gyrox = gyrox  * PI / 180.0f;

gyroy = gyroy * PI / 180.0f;

gyroz = gyroz * PI / 180.0f;

// Quaternion conversion function

MadgwickQuaternionUpdate(ax, ay, az, gyrox, gyroy, gyroz);
```

Quaternion Conversion Function

Quaternion filter computational function.

Define variables, including bias, auxiliary operation values, norm and Jacobian elements.

Flow chart

---

1. First calculate the vector norm of acceleration, and its norm is the length of vector. Here is the formula:

$$norm = sqrt(ax * ax + ay * ay + az * az)$$

(ax, ay and az respectively means the acceleration on axis x, y and z)

2. Calculate Jacobian.
3. Compute the gradient via Jacobian multiplication.
4. Normalize gradient.
5. Compute estimated gyroscope biases.
6. Compute and remove gyroscope biases.
7. Compute the quaternion derivative.
8. Integrate estimated quaternion derivative.
9. Normalize the quaternion.

Code:

```
// Implementation of Sebastian Madgwick's "...efficient orientation filter for... inertial/magnetic sensor arrays"

// which fuses acceleration and rotation rate to produce a quaternion-based estimate of relative

// device orientation -- which can be converted to yaw, pitch, and roll. Useful for stabilizing quadcopters, etc.

// The performance of the orientation filter is at least as good as conventional Kalman-based filtering algorithms

// but is much less computationally intensive---it can be performed on a 3.3 V Pro Mini operating at 8 MHz!

void MadgwickQuaternionUpdate(float ax, float ay, float az, float gyrox, float gyroy, float gyroz)

{

// short name local variable for readability

float q1 = q[0], q2 = q[1], q3 = q[2], q4 = q[3];

// vector norm

```

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```
float norm;

// objective function elements

float f1, f2, f3;

// objective function Jacobian elements

float J_11or24, J_12or23, J_13or22, J_14or21, J_32, J_33;

float qDot1, qDot2, qDot3, qDot4;

float hatDot1, hatDot2, hatDot3, hatDot4;

// gyro bias error

float gerrx, gerry, gerrz, gbiasx, gbiasy, gbiasz;

// Auxiliary variables to avoid repeated arithmetic

float _halfq1 = 0.5f * q1;

float _halfq2 = 0.5f * q2;

float _halfq3 = 0.5f * q3;

float _halfq4 = 0.5f * q4;

float _2q1 = 2.0f * q1;

float _2q2 = 2.0f * q2;

float _2q3 = 2.0f * q3;

float _2q4 = 2.0f * q4;

float _2q1q3 = 2.0f * q1 * q3;

float _2q3q4 = 2.0f * q3 * q4;


// Normalize accelerometer measurement

norm = sqrt(ax * ax + ay * ay + az * az);

if (norm == 0.0f) return; // handle NaN

norm = 1.0f/norm;

ax *= norm;
```

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```
ay *= norm;

az *= norm;



// Compute the objective function and Jacobian

f1 = _2q2 * q4 - _2q1 * q3 - ax;

f2 = _2q1 * q2 + _2q3 * q4 - ay;

f3 = 1.0f - _2q2 * q2 - _2q3 * q3 - az;

J_11or24 = _2q3;

J_12or23 = _2q4;

J_13or22 = _2q1;

J_14or21 = _2q2;

J_32 = 2.0f * J_14or21;

J_33 = 2.0f * J_11or24;



// Compute the gradient (matrix multiplication)

hatDot1 = J_14or21 * f2 - J_11or24 * f1;

hatDot2 = J_12or23 * f1 + J_13or22 * f2 - J_32 * f3;

hatDot3 = J_12or23 * f2 - J_33 *f3 - J_13or22 * f1;

hatDot4 = J_14or21 * f1 + J_11or24 * f2;



// Normalize the gradient

norm = sqrt(hatDot1 * hatDot1 + hatDot2 * hatDot2 + hatDot3 * hatDot3 + hatDot4 *
↪hatDot4);

hatDot1 /= norm;

hatDot2 /= norm;

hatDot3 /= norm;

hatDot4 /= norm;
```

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```
// Compute estimated gyroscope biases
gerrx = _2q1 * hatDot2 - _2q2 * hatDot1 - _2q3 * hatDot4 + _2q4 * hatDot3;
gerry = _2q1 * hatDot3 + _2q2 * hatDot4 - _2q3 * hatDot1 - _2q4 * hatDot2;
gerrz = _2q1 * hatDot4 - _2q2 * hatDot3 + _2q3 * hatDot2 - _2q4 * hatDot1;

// Compute and remove gyroscope biases
gbiasx += gerrx * deltat * zeta;
gbiasy += gerry * deltat * zeta;
gbiasz += gerrz * deltat * zeta;
gyrox -= gbiasx;
gyroy -= gbiasy;
gyroz -= gbiasz;

// Compute the quaternion derivative
qDot1 = -_halfq2 * gyrox - _halfq3 * gyroy - _halfq4 * gyroz;
qDot2 =  _halfq1 * gyrox + _halfq3 * gyroz - _halfq4 * gyroy;
qDot3 =  _halfq1 * gyroy - _halfq2 * gyroz + _halfq4 * gyrox;
qDot4 =  _halfq1 * gyroz + _halfq2 * gyroy - _halfq3 * gyrox;

// Compute then integrate estimated quaternion derivative
q1 += (qDot1 -(beta * hatDot1)) * deltat;
q2 += (qDot2 -(beta * hatDot2)) * deltat;
q3 += (qDot3 -(beta * hatDot3)) * deltat;
q4 += (qDot4 -(beta * hatDot4)) * deltat;
```

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```
// Normalize the quaternion

norm = sqrt(q1 * q1 + q2 * q2 + q3 * q3 + q4 * q4);    // normalize quaternion

norm = 1.0f/norm;

q[0] = q1 * norm;

q[1] = q2 * norm;

q[2] = q3 * norm;

q[3] = q4 * norm;

}
```

Convert Quaternion to Euler Angle

Conversion Formula:

$$Yaw(z) = atan2(2 * (w * z + x * y), 1 - 2 * (z^2 + x^2))$$

$$Pitch(y) = asin(2 * (w * y - z * x))$$

$$Roll(x) = atan2(2 * (w * x + y * z), 1 - 2 * (x^2 + y^2))$$

Code:

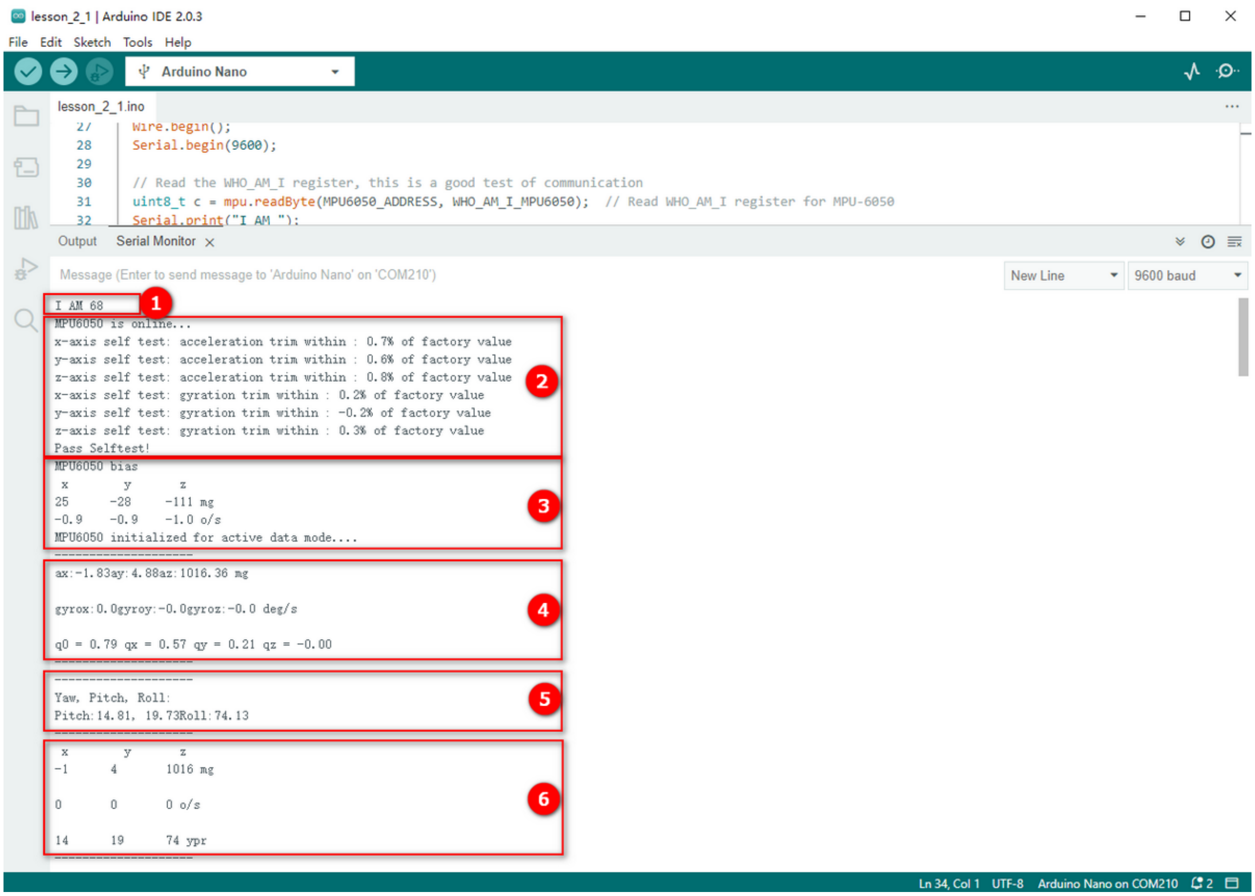
```
yaw = atan2(2.0f * (q[1] * q[2] + q[0] * q[3]), q[0] * q[0] + q[1] * q[1] - q[2] * q[2] -
↪ q[3] * q[3]);

pitch = -asin(2.0f * (q[1] * q[3] - q[0] * q[2]));

roll  = atan2(2.0f * (q[0] * q[1] + q[2] * q[3]), q[0] * q[0] - q[1] * q[1] - q[2] *␣
↪q[2] + q[3] * q[3]);


pitch *= 180.0f / PI;

yaw  *= 180.0f / PI;

roll  *= 180.0f / PI;
```

6.5.5 Test Result

Download the code to Arduino NANO.

Keep MPU6050 balanced and press the reset button.

Wait for 3~5s and open the serial port.



1. Acquire ID0x68 of MPU6050
2. Self-test and print the test value.
3. Calibrate and print the calibration value, and then initialize.
4. Acquire accelerometer and gyroscope data and the quaternion.
5. Acquire the converted Euler Angle.
6. Acquire the data of accelerometer, gyroscope and Euler Angle in axis X, Y and Z.

6.5.6 Test Code:

Please refer to the folder lesson_2_1.

[lesson_2_1.ino]:

```
#include "MPU6050.h"

MPU6050lib mpu;

float aRes, gRes;        // scale resolutions per LSB for the sensors

int16_t accelCount[3];      // Stores the 16-bit signed accelerometer sensor output

int16_t gyroCount[3];      // Stores the 16-bit signed gyro sensor output

float ax, ay, az;        // Stores the real accel value in g's

float gyrox, gyroy, gyroz;    // Stores the real gyro value in degrees per seconds

float gyroBias[3] = {0, 0, 0};

float accelBias[3] = {0, 0, 0}; // correct gyro and accelerometer bias

int16_t tempCount;        // Stores the real internal chip temperature in degrees Celsius

float temperature;

float SelfTest[6];

float q[4] = {1.0f, 0.0f, 0.0f, 0.0f};// vector to hold quaternion

float pitch, yaw, roll;

// parameters for 6 DoF sensor fusion calculations

float GyroMeasError = PI * (40.0f / 180.0f);    // gyroscope measurement error in rads/s␣
↪(start at 60 deg/s), then reduce after ~10 s to 3

float beta = sqrt(3.0f / 4.0f) * GyroMeasError;  // compute beta()

float GyroMeasDrift = PI * (2.0f / 180.0f);    // gyroscope measurement drift in rad/s/s␣
↪(start at 0.0 deg/s/s)

float zeta = sqrt(3.0f / 4.0f) * GyroMeasDrift;  // compute zeta, the other free␣
↪parameter in the Madgwick scheme usually set to a small or zero value

float deltat = 0.0f;               // integration interval for both filter schemes

uint32_t lastUpdate = 0, firstUpdate = 0;     // used to calculate integration interval

uint32_t Now = 0;                // used to calculate integration interval
```

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```
void setup()

{

 Wire.begin();

 Serial.begin(9600);



 // Read the WHO_AM_I register, this is a good test of communication

 uint8_t c = mpu.readByte(MPU6050_ADDRESS, WHO_AM_I_MPU6050); // Read WHO_AM_I register␣
↪for MPU-6050

 Serial.print("I AM ");

 Serial.println(c, HEX);



 mpu.settings(AFS_8G, GFS_250DPS);

 if (c == 0x68) // WHO_AM_I should always be 0x68

 {

  Serial.println("MPU6050 is online...");

  // Start by performing self test and reporting values

  mpu.MPU6050SelfTest(SelfTest);

  Serial.print("x-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[0],1); Serial.println("% of factory value");

  Serial.print("y-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[1],1); Serial.println("% of factory value");

  Serial.print("z-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[2],1); Serial.println("% of factory value");

  Serial.print("x-axis self test: gyration trim within : "); Serial.print(SelfTest[3],1);
↪ Serial.println("% of factory value");

  Serial.print("y-axis self test: gyration trim within : "); Serial.print(SelfTest[4],1);
↪ Serial.println("% of factory value");

  Serial.print("z-axis self test: gyration trim within : "); Serial.print(SelfTest[5],1);
↪ Serial.println("% of factory value");
```

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```
 if (SelfTest[0] < 1.0f && SelfTest[1] < 1.0f && SelfTest[2] < 1.0f && SelfTest[3] < 1.
↪0f && SelfTest[4] < 1.0f && SelfTest[5] < 1.0f) {

  Serial.println("Pass Selftest!");

  // Calibrate gyro and accelerometer, load biases in bias registers

  mpu.calibrateMPU6050(gyroBias, accelBias);

  Serial.println("MPU6050 bias");

  Serial.println(" x\t  y\t  z  ");

  Serial.print((int)(1000 * accelBias[0])); Serial.print('\t');

  Serial.print((int)(1000 * accelBias[1])); Serial.print('\t');

  Serial.print((int)(1000 * accelBias[2]));

  Serial.println(" mg");



  Serial.print(gyroBias[0], 1); Serial.print('\t');

  Serial.print(gyroBias[1], 1); Serial.print('\t');

  Serial.print(gyroBias[2], 1);

  Serial.println(" o/s");



  mpu.settings(AFS_2G, GFS_250DPS);

  mpu.initMPU6050();

  // Initialize device for active mode read of accelerometer , gyroscope, and␣
↪temperature



  Serial.println("MPU6050 initialized for active data mode....");

 }

}

else
```

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```
 {
  Serial.print("Could not connect to MPU6050: 0x");
  Serial.println(c, HEX);
  while(1); // Loop forever if communication doesn't happen
 }
}

void loop()
{
 // If data ready bit set, all data registers have new data
 if (mpu.readByte(MPU6050_ADDRESS, INT_STATUS) & 0x01) { // check if data ready interrupt
  mpu.readAccelData(accelCount);   // Read the x/y/z adc values
  aRes = mpu.getAres();       // Acquire the converted value

  // Now we'll calculate the accleration value into actual g's
  ax = (float)accelCount[0] * aRes; // get actual g value, this depends on scale being␣
↪set
  ay = (float)accelCount[1] * aRes;
  az = (float)accelCount[2] * aRes;

  mpu.readGyroData(gyroCount);    // Read the x/y/z adc values
  gRes = mpu.getGres();       // Acquire the converted value

  // Calculate the gyro value into actual degrees per second
  gyrox = (float)gyroCount[0] * gRes; // get actual gyro value, this depends on scale␣
↪being set
  gyroy = (float)gyroCount[1] * gRes;
```

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```
 gyroz = (float)gyroCount[2] * gRes;


 tempCount = mpu.readTempData(); // Read the x/y/z adc values
 temperature = ((float) tempCount) / 340. + 36.53; // Temperature in degrees Centigrade
}
// Acquire the current time of the system in ms
Now = micros();
// set integration time by time elapsed since last filter update
deltat = ((Now - lastUpdate) / 1000000.0f);
lastUpdate = Now;
if(lastUpdate - firstUpdate > 10000000uL) {
 beta = 0.041; // decrease filter gain after stabilized
 zeta = 0.015; // increase gyro bias drift gain after stabilized
}
// Convert the gyroscope data to radians
gyrox = gyrox  * PI / 180.0f;
gyroy = gyroy * PI / 180.0f;
gyroz = gyroz * PI / 180.0f;
// Quaternion conversion function
MadgwickQuaternionUpdate(ax, ay, az, gyrox, gyroy, gyroz);


Serial.println("--------------------");
Serial.print("ax:"); Serial.print((int)1000*ax);
Serial.print("ay:"); Serial.print((int)1000*ay);
Serial.print("az:"); Serial.print((int)1000*az); Serial.println(" mg");
```

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```
Serial.println("  ");

Serial.print("gyrox:"); Serial.print( gyrox, 1);

Serial.print("gyroy:"); Serial.print( gyroy, 1);

Serial.print("gyroz:"); Serial.print( gyroz, 1); Serial.println(" deg/s");



Serial.println("  ");

Serial.print(" q0 = "); Serial.print(q[0]);

Serial.print(" qx = "); Serial.print(q[1]);

Serial.print(" qy = "); Serial.print(q[2]);

Serial.print(" qz = "); Serial.println(q[3]);

Serial.println("--------------------");



// Define output variables from updated quaternion---these are Tait-Bryan angles,␣
↪commonly used in aircraft orientation.

// In this coordinate system, the positive z-axis is down toward Earth.

// Yaw is the angle between Sensor x-axis and Earth magnetic North (or true North if␣
↪corrected for local declination, looking down on the sensor positive yaw is␣
↪counterclockwise.

// Pitch is angle between sensor x-axis and Earth ground plane, toward the Earth is␣
↪positive, up toward the sky is negative.

// Roll is angle between sensor y-axis and Earth ground plane, y-axis up is positive␣
↪roll.

// These arise from the definition of the homogeneous rotation matrix constructed from␣
↪quaternions.

// Tait-Bryan angles as well as Euler angles are non-commutative; that is, the get the␣
↪correct orientation the rotations must be

// applied in the correct order which for this configuration is yaw, pitch, and then␣
↪roll.

yaw   = atan2(2.0f * (q[1] * q[2] + q[0] * q[3]), q[0] * q[0] + q[1] * q[1] - q[2] *␣
↪q[2] - q[3] * q[3]);

pitch = -asin(2.0f * (q[1] * q[3] - q[0] * q[2]));
```

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```
roll  = atan2(2.0f * (q[0] * q[1] + q[2] * q[3]), q[0] * q[0] - q[1] * q[1] - q[2] *␣
↪q[2] + q[3] * q[3]);



pitch *= 180.0f / PI;

yaw   *= 180.0f / PI;

roll  *= 180.0f / PI;



Serial.println("--------------------");

// Serial.println("Yaw\t Pitch\t Roll: ");

Serial.print("Yaw:");

Serial.print(yaw, 2);

Serial.print("°");

Serial.print("\tPitch:");

Serial.print(pitch, 2);

Serial.print("°");

Serial.print("\tRoll:");

Serial.print(roll, 2);

Serial.println("°");

Serial.println("--------------------");



Serial.println(" x\t  y\t  z  ");



Serial.print((int)(1000 * ax)); Serial.print('\t');

Serial.print((int)(1000 * ay)); Serial.print('\t');

Serial.print((int)(1000 * az));

Serial.println(" mg");
```

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```
 Serial.println("  ");

 Serial.print((int)(gyrox)); Serial.print('\t');

 Serial.print((int)(gyroy)); Serial.print('\t');

 Serial.print((int)(gyroz));

 Serial.println(" o/s");

 Serial.println("  ");

 Serial.print((int)(yaw)); Serial.print('\t');

 Serial.print((int)(pitch)); Serial.print('\t');

 Serial.print((int)(roll));

 Serial.println(" ypr");

 Serial.println("--------------------");



 delay(100);

}



// Implementation of Sebastian Madgwick's "...efficient orientation filter for...␣
↪inertial/magnetic sensor arrays"

// which fuses acceleration and rotation rate to produce a quaternion-based estimate of␣
↪relative

// device orientation -- which can be converted to yaw, pitch, and roll. Useful for␣
↪stabilizing quadcopters, etc.

// The performance of the orientation filter is at least as good as conventional Kalman-
↪based filtering algorithms

// but is much less computationally intensive---it can be performed on a 3.3 V Pro Mini␣
↪operating at 8 MHz!

void MadgwickQuaternionUpdate(float ax, float ay, float az, float gyrox, float gyroy,␣
↪float gyroz)

{

 float q1 = q[0], q2 = q[1], q3 = q[2], q4 = q[3];     // short name local variable for␣
↪readability
```

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```
float norm;                             // vector norm

float f1, f2, f3;                         // objective function elements

float J_11or24, J_12or23, J_13or22, J_14or21, J_32, J_33; // objective function␣
↪Jacobian elements

float qDot1, qDot2, qDot3, qDot4;

float hatDot1, hatDot2, hatDot3, hatDot4;

float gerrx, gerry, gerrz, gbiasx, gbiasy, gbiasz;     // gyro bias error



// Auxiliary variables to avoid repeated arithmetic

float _halfq1 = 0.5f * q1;

float _halfq2 = 0.5f * q2;

float _halfq3 = 0.5f * q3;

float _halfq4 = 0.5f * q4;

float _2q1 = 2.0f * q1;

float _2q2 = 2.0f * q2;

float _2q3 = 2.0f * q3;

float _2q4 = 2.0f * q4;

float _2q1q3 = 2.0f * q1 * q3;

float _2q3q4 = 2.0f * q3 * q4;



// Normalise accelerometer measurement

norm = sqrt(ax * ax + ay * ay + az * az);

if (norm == 0.0f) return; // handle NaN

norm = 1.0f/norm;

ax *= norm;

ay *= norm;
```

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```
az *= norm;


// Compute the objective function and Jacobian

f1 = _2q2 * q4 - _2q1 * q3 - ax;

f2 = _2q1 * q2 + _2q3 * q4 - ay;

f3 = 1.0f - _2q2 * q2 - _2q3 * q3 - az;

J_11or24 = _2q3;

J_12or23 = _2q4;

J_13or22 = _2q1;

J_14or21 = _2q2;

J_32 = 2.0f * J_14or21;

J_33 = 2.0f * J_11or24;


// Compute the gradient (matrix multiplication)

hatDot1 = J_14or21 * f2 - J_11or24 * f1;

hatDot2 = J_12or23 * f1 + J_13or22 * f2 - J_32 * f3;

hatDot3 = J_12or23 * f2 - J_33 *f3 - J_13or22 * f1;

hatDot4 = J_14or21 * f1 + J_11or24 * f2;


// Normalize the gradient

norm = sqrt(hatDot1 * hatDot1 + hatDot2 * hatDot2 + hatDot3 * hatDot3 + hatDot4 *
↪hatDot4);

hatDot1 /= norm;

hatDot2 /= norm;

hatDot3 /= norm;

hatDot4 /= norm;
```

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```
// Compute estimated gyroscope biases
gerrx = _2q1 * hatDot2 - _2q2 * hatDot1 - _2q3 * hatDot4 + _2q4 * hatDot3;
gerry = _2q1 * hatDot3 + _2q2 * hatDot4 - _2q3 * hatDot1 - _2q4 * hatDot2;
gerrz = _2q1 * hatDot4 - _2q2 * hatDot3 + _2q3 * hatDot2 - _2q4 * hatDot1;

// Compute and remove gyroscope biases
gbiasx += gerrx * deltat * zeta;
gbiasy += gerry * deltat * zeta;
gbiasz += gerrz * deltat * zeta;
gyrox -= gbiasx;
gyroy -= gbiasy;
gyroz -= gbiasz;

// Compute the quaternion derivative
qDot1 = -_halfq2 * gyrox - _halfq3 * gyroy - _halfq4 * gyroz;
qDot2 =  _halfq1 * gyrox + _halfq3 * gyroz - _halfq4 * gyroy;
qDot3 =  _halfq1 * gyroy - _halfq2 * gyroz + _halfq4 * gyrox;
qDot4 =  _halfq1 * gyroz + _halfq2 * gyroy - _halfq3 * gyrox;
// Compute then integrate estimated quaternion derivative
q1 += (qDot1 -(beta * hatDot1)) * deltat;
q2 += (qDot2 -(beta * hatDot2)) * deltat;
q3 += (qDot3 -(beta * hatDot3)) * deltat;
q4 += (qDot4 -(beta * hatDot4)) * deltat;
// Normalize the quaternion
norm = sqrt(q1 * q1 + q2 * q2 + q3 * q3 + q4 * q4);    //  normalise quaternion
norm = 1.0f/norm;
```

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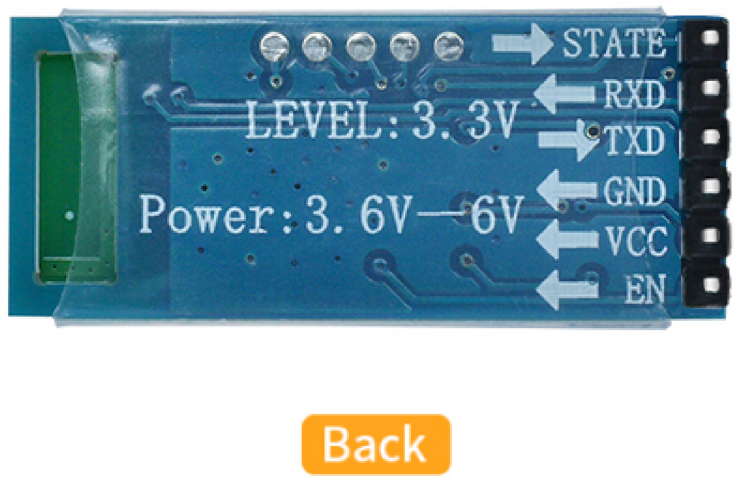
```
 q[0] = q1 * norm;

 q[1] = q2 * norm;

 q[2] = q3 * norm;

 q[3] = q4 * norm;

}
```

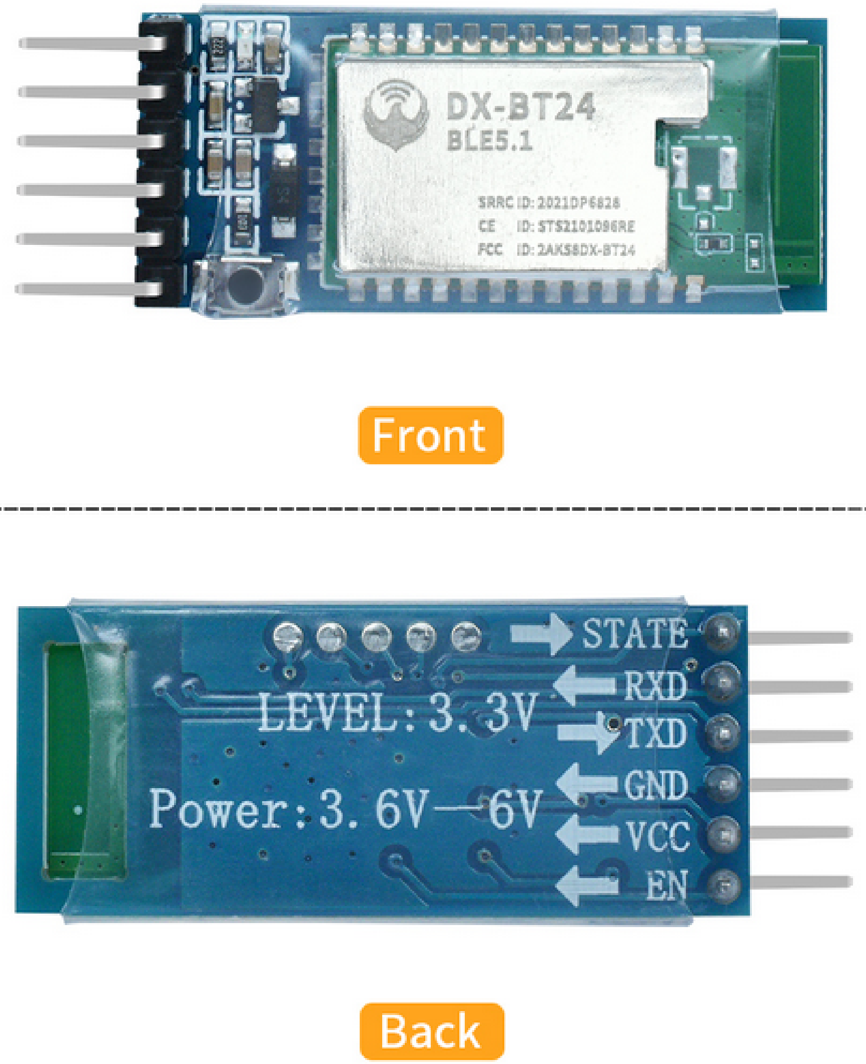
6.6 BT Receiving and Sending

6.6.1 Bluetooth Module

Host Bluetooth Module (Straight pins):



Slave Bluetooth Module (Curved pins):



DX-BT24 adopts DIALOG 14531 chip, which supports AT commands and UART communication, and obeys BT BLE5.1 protocol.

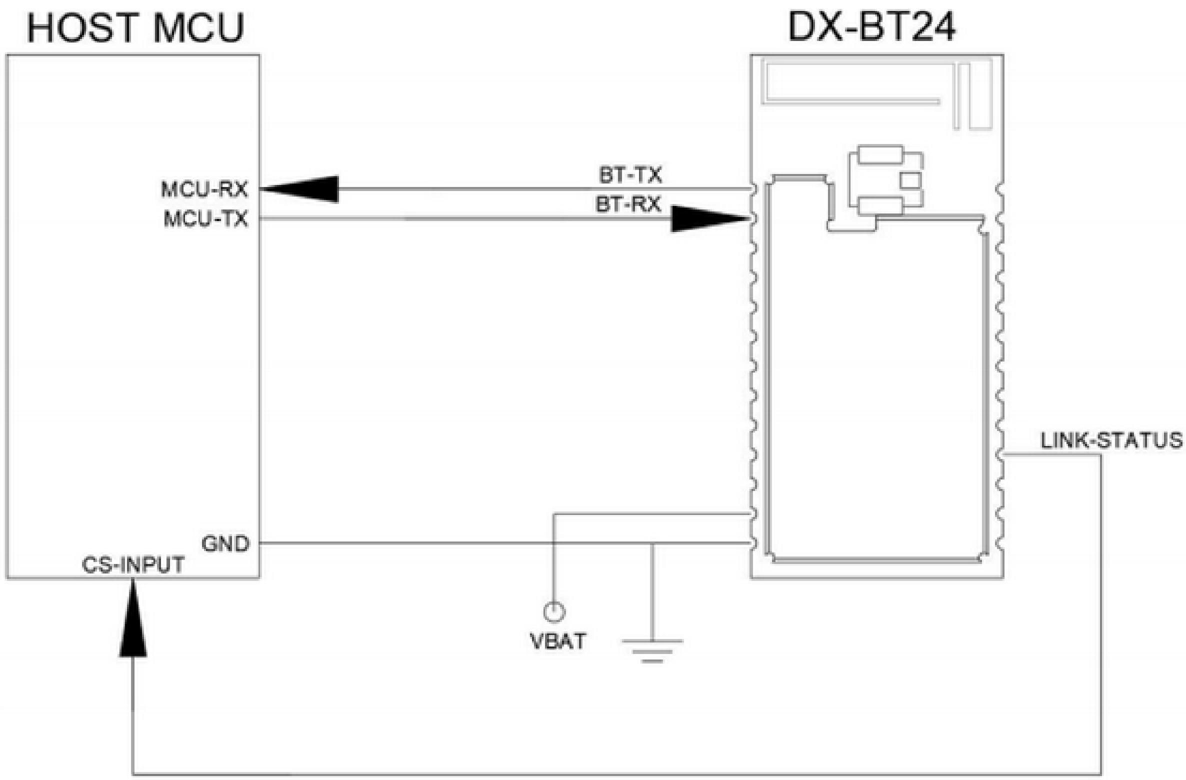
The most important merits are its flexibility to adjust baud rate and device name, low costs, low consumption as well as high receiving sensitivity.

Features:

- DIALOG14531 main control chip
- BT BLE5.1 protocol
- Minimum power consumption: 2 uA.
- Visual distance: 90M for slave module; 20M for main module

- Transmitting speed: 10K Bytes/s
- UART communication
- Support iBeacon mode programs
- Direct-drive and single-host programs for options
- One host - to - many slave modules programs

Circuit diagram:



Working modes:

Modes	Functions
Normal Mode	All functions of peripheral interfaces are in a normal state.
Low Consumption Mode	Disconnection: Only broadcast is enabled, while all peripheral interfaces are disabled.Connection: Same as the normal mode.
Sleep Mode	All RAMs stop working.Only a built-in ticking clock is left to awakening the module.Peripheral interfaces and the broadcast are all disabled.

UART interface: the default parameter of the serial port: 9600bps/8/n/1 (Baud rate/data bit/none check/stop bit).

Parameters	Values
Baud rate	Minimum: 2400baud (1%Error),Standard: 9600baud (1%Error),Maximum: 115200baud (1%Error)
Parity check	None/ even or odd
Stop bit	1/2
Bits for each channel	8

BT control: Control BT by AT commands.

AT command (AT function and AT parameter) is a collection to control common Bluetooth operations, including connecting and disconnecting, searching and pairing, sending and receiving.

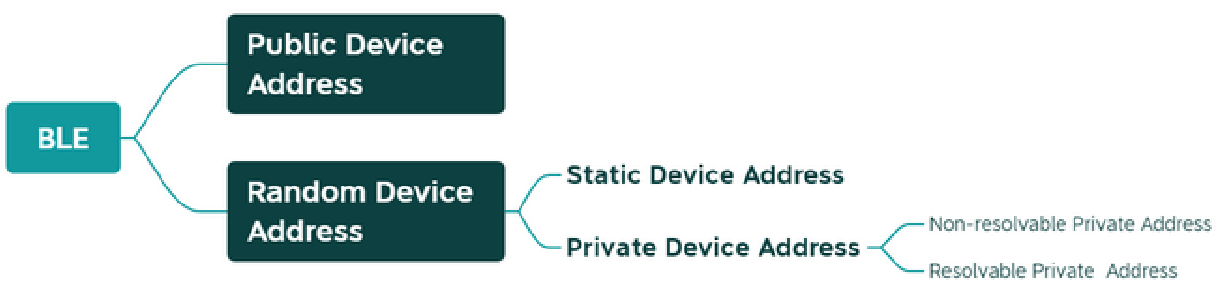
AT parameter specifies AT function, such as pairing codes, connecting address and time interval as well as the length of sending data.

AT command and transmitting mode:

- AT command mode: The module will response commands if it disconnects any slave devices.
- Transmitting mode: The module will transmit data if it connects devices.

Connections between BT devices: A device address (MAC address) identifies a unique physical device. In other words, uniqueness (in a certain distance) is a very significant feature of an address.

A BLE device utilizes one (or both) of the two types of addresses: **Public Device Address** and **Random Device Address.**



Public Device Address:

It is originated from the classic Bluetooth (BR/EDR) address, which is a 48bits (6 bytes) number and also called“48-bit universal LAN MAC address”(same as computer MAC address).

Normally, the address holder must apply to IEEE to pay for it to ensure its uniqueness.

Static Device Address:

It is generated at random during device working.

6.6.2 AT Commands

AT commands are text instructions to integrate the computer and Bluetooth via serial port, and they are used for status and function enquiry, parameter configuration and connection state.

Generally, we connect device to Bluetooth through USB-to-serial port to manipulate the BT module.

AT Command Format for Sending:

AT+Command<param1,param2,param3> <CR><CF>

- All commands begin with"AT"and end in"<CR><LF>". In following figures we will omit "<CR><LF>".
- All letters should be capitals.
- Contents in"<>"means options.
- If a command includes multiple parameters, they should be separated by"".
- Real commands exclude"<>".
- <CR> indicates a carriage-return-character"\r"and OXOD symbolizes hexadecimal.
- The line-feed-character is signaled as <LF> and OXOA represents hexadecimal.
- If commands execute successfully, the relevant output will end with OK. If not, it outputs EEROR=<> (error codes in"<>").

AT Command Format for Receiving:

+Indication<=param1,param2,param3><CR><CF>

- A response command starts with "+" and ends in <CR><CF>.
- "=" follows response parameters.
- If a response includes multiple parameters, they will be separated by "".

An AT Command Example:

Revise the Bluetooth name as 1234

Send: AT+NAME1234

Receive+NAME=1234

OK

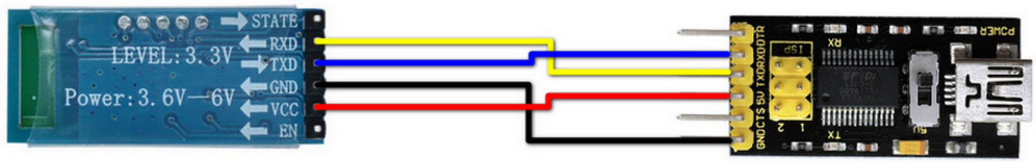
6.6.3 Wiring

Connect Bluetooth to the device via USB-to-serial port module. Note: Installations of hosts and slave devices are totally same.

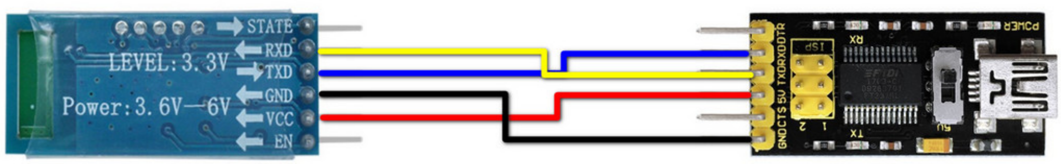
Keyestudio FTDI (original chips) Basic Program:

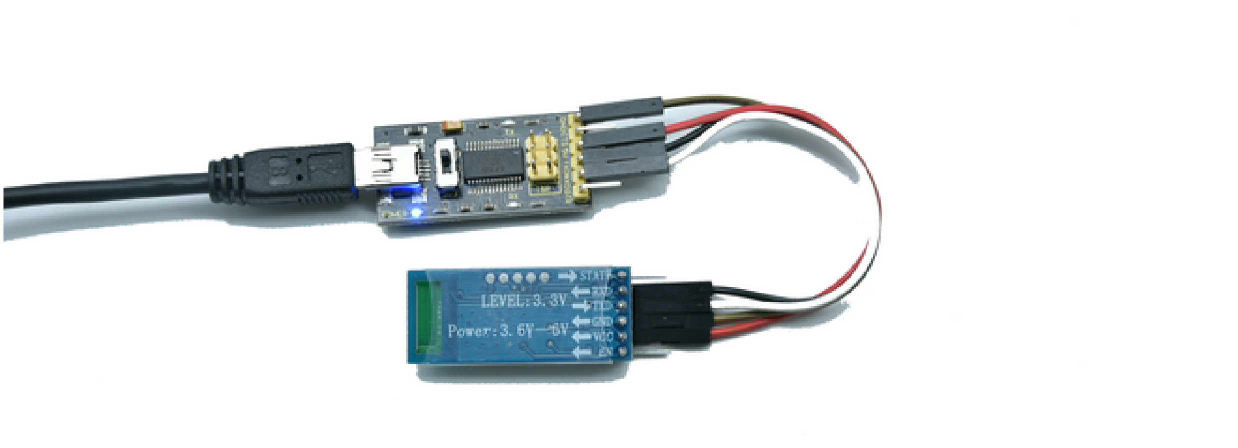
https://www.keyestudio.com/search/?Keyword=ks0277

Master



Slave





Connection Description:

USB-to-serial port	Host & slave Bluetooth
RX	TX
TX	RX
VCC	VCC
GND	GND

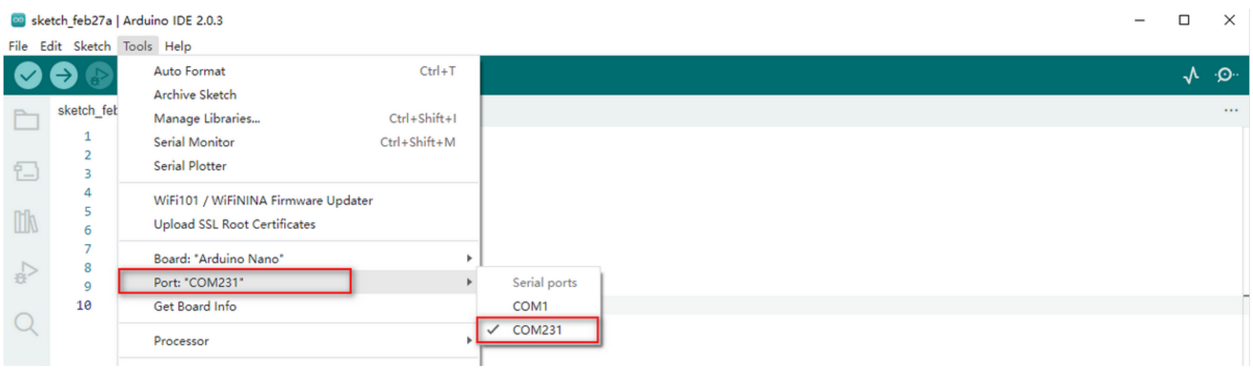
6.6.4 Control BT by AT Commands

The Bluetooth responds to AT commands when it disconnects to any slave devices.

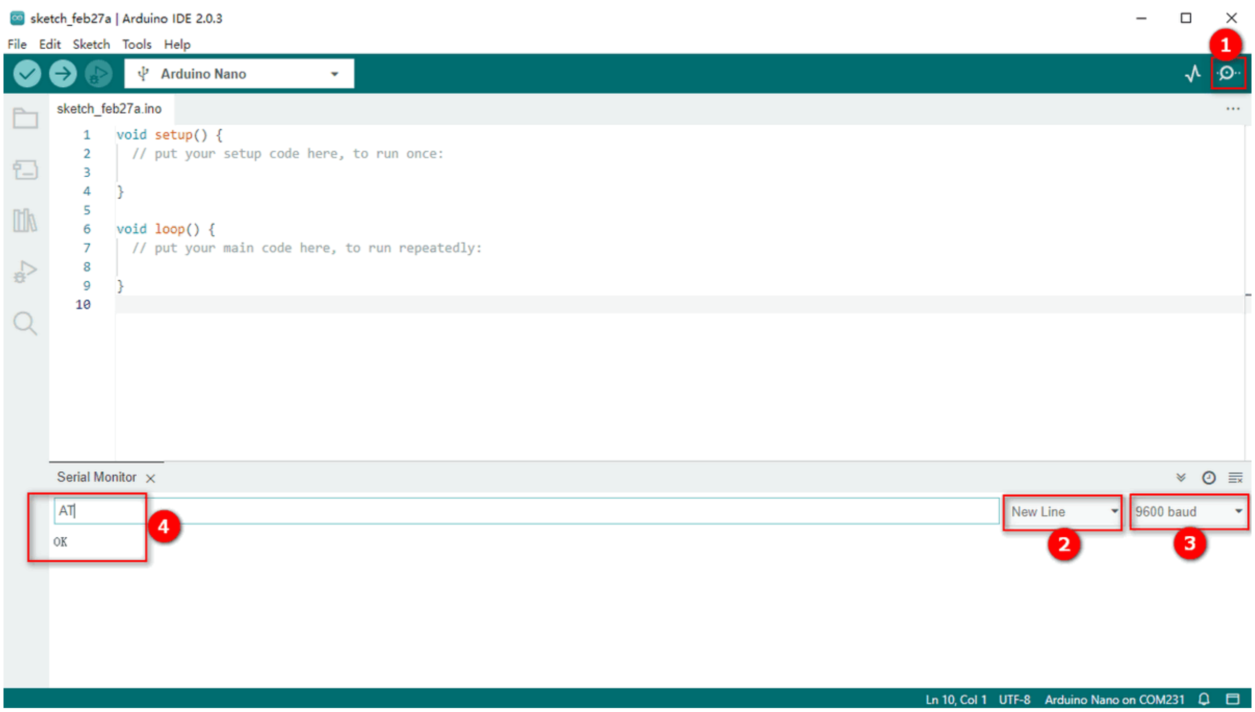
Note: All letters in a command should be capitals!

Operate Host Devices

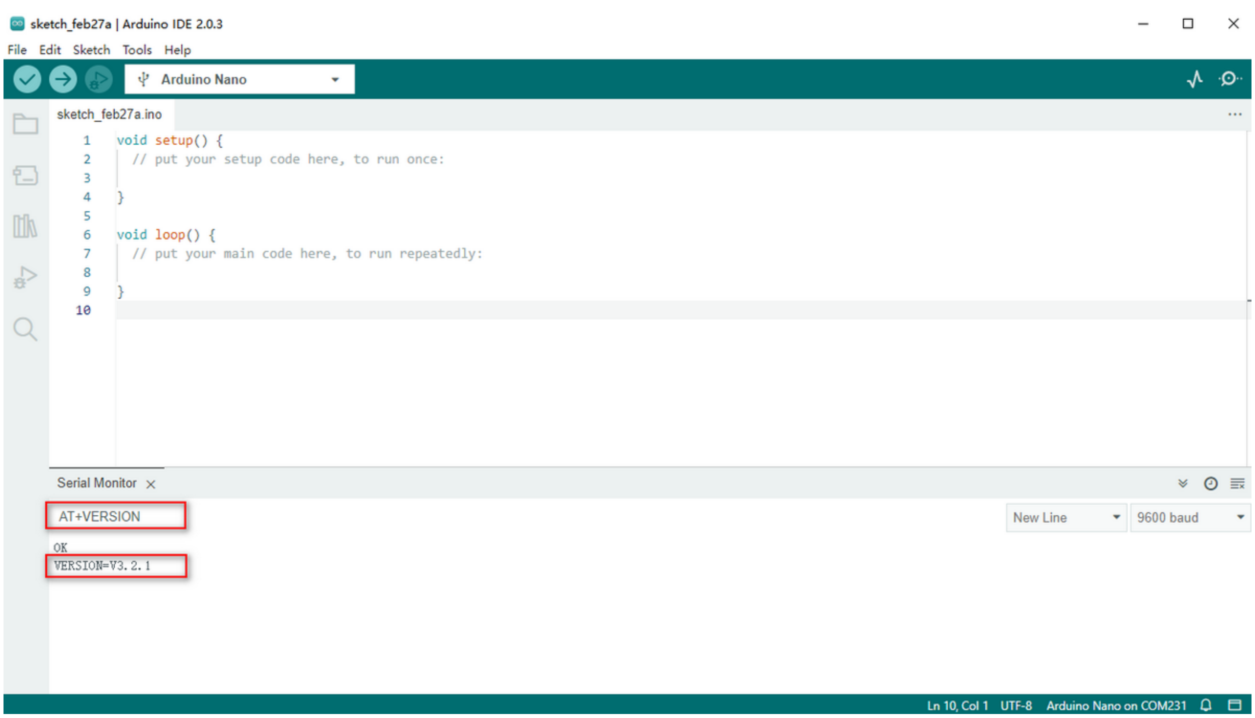
Create a blank project in Arduino IDE to select the Port:



Set baud rate as 9600 (the host is 9600 by default), and input AT to send your command. If the module receives it, OK will be output.

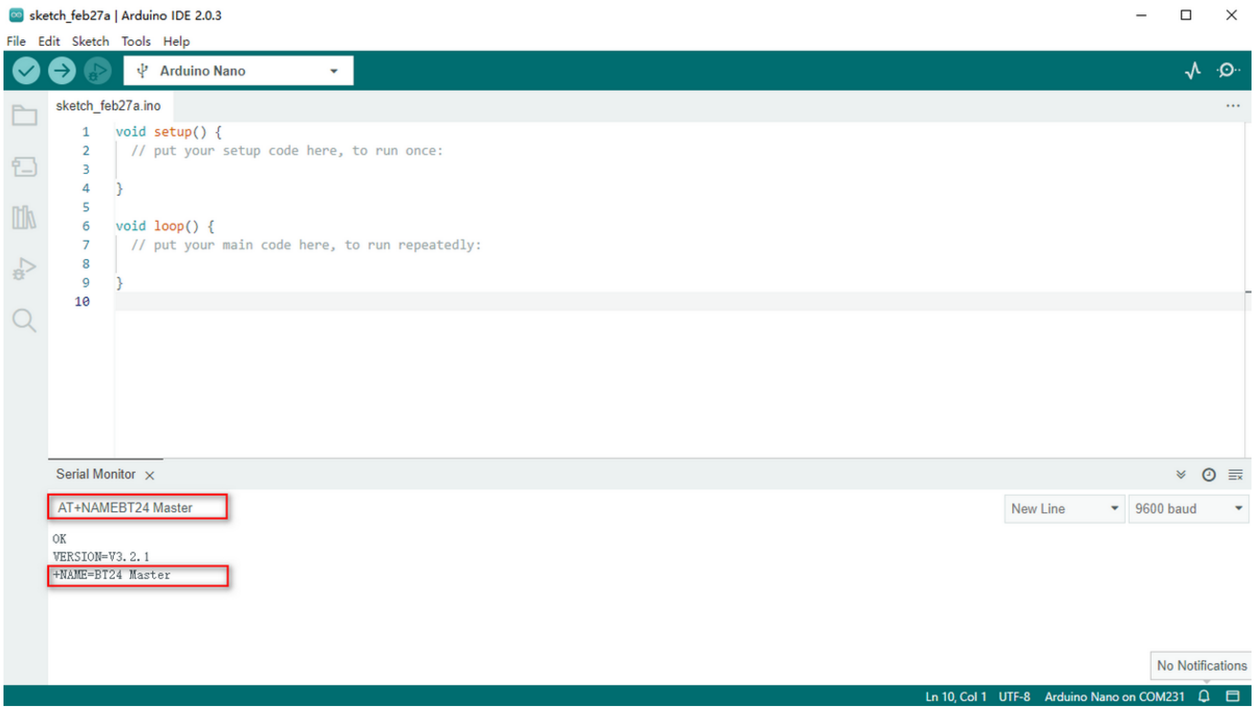


Query version number: Input AT+VERSION to display the version number .



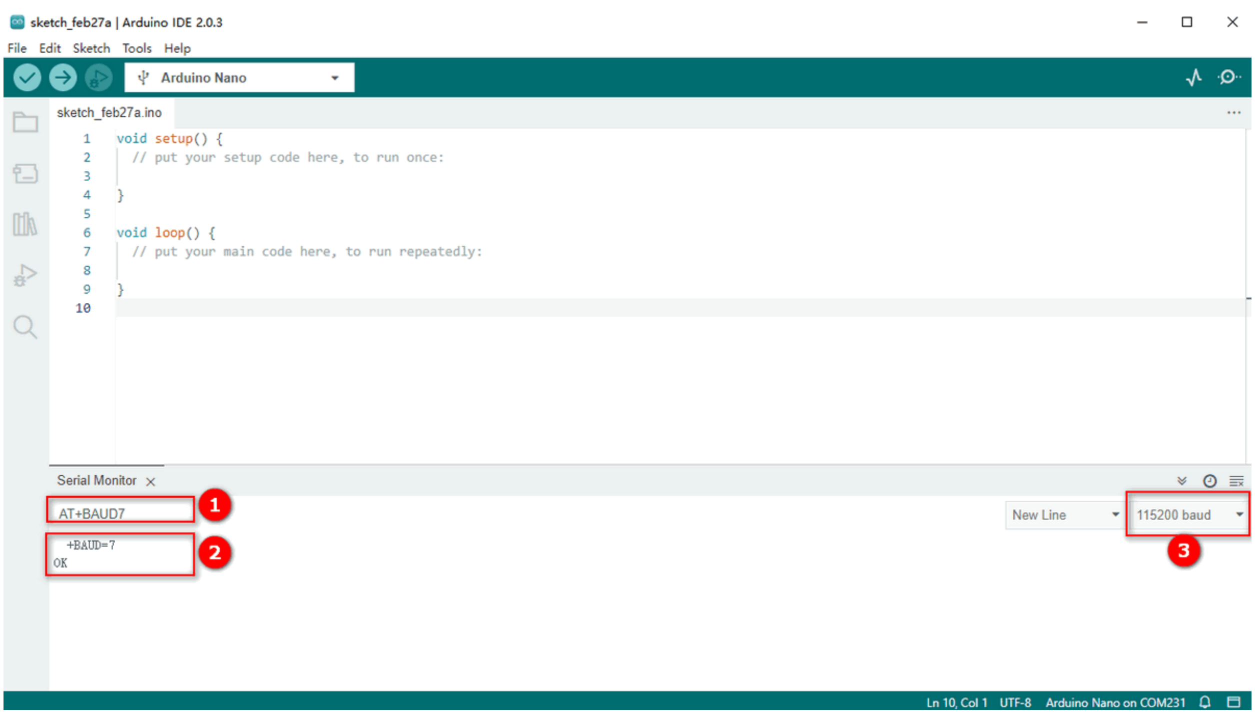
Revise BT name: Input AT+NAMEBT24 Master to revise it name as BT24 Master then it will be output.

Query BT name: AT+NAME.



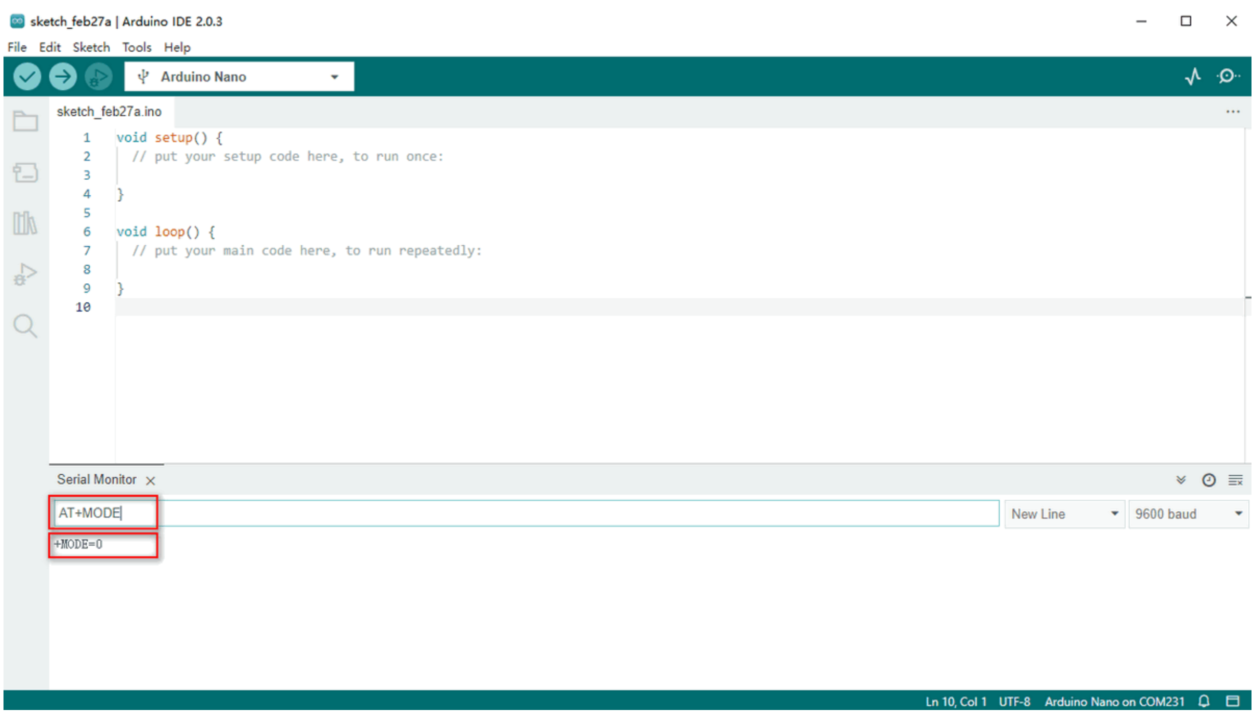
NO.	1	2	3	4	5	6	7	Default Value
Baud Rate	2400	4800	9600	19200	38400	57600	115200	9600

Set baud rate: Input AT+BAUD7 to set baud rate to 115200. If the module communicates with other devices, their baud rate should also be 115200.



Set searching mode:

NO.	Functions	Commands	Description
1	Query thesearching mode	AT+MODE	Query the current searching mode.
2	Normal mode(default)	AT+MODE	All surrounding BLE devices can be searched. Note: Connect BT24 series only.
3	Manufacturer information-filter mode	AT+MODE	Filter manufacturer information: Only information of BT24 series can be searched.
4	pairing mode	AT+MODE	Only pairing slave devices can be detected.
5	Obtain IBEACON information	AT+MODE	Surrounding IBeacon broadcasting package information can be obtained by scanning.



Operate Slave Devices

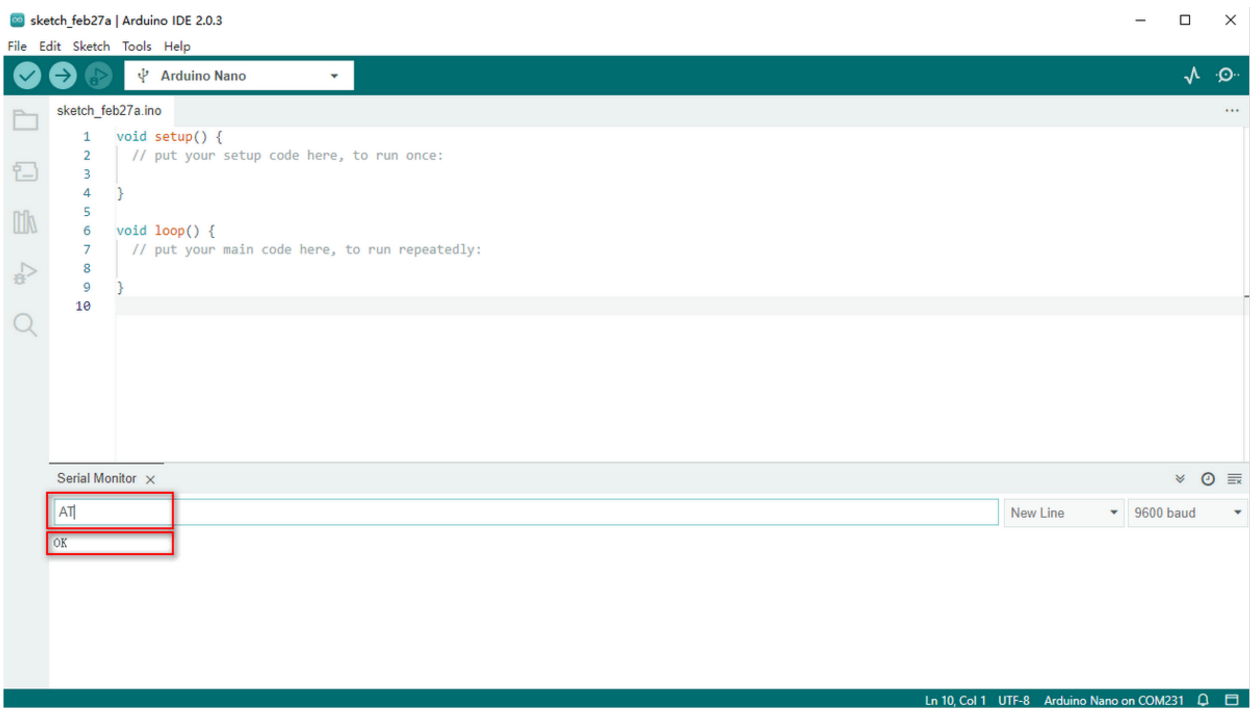
Note: This BT24 module is not included in kits.

Keyestudio bt-24 Module RS232/TTL to UART:

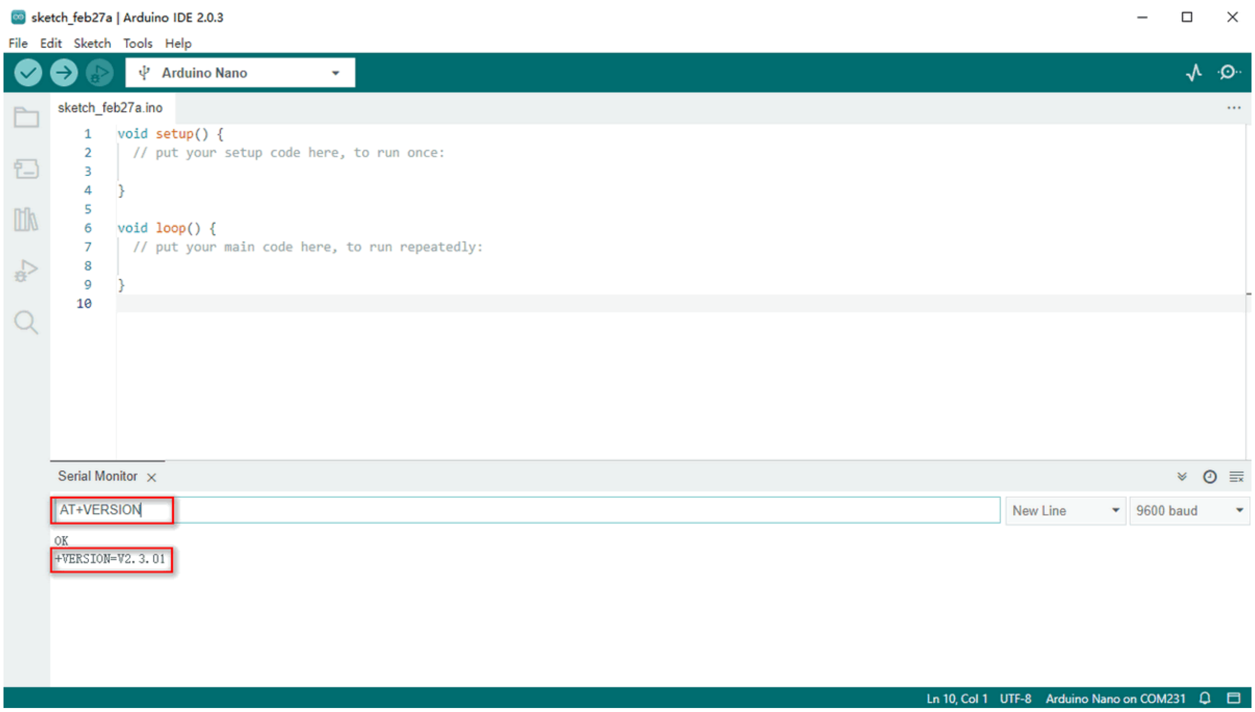
https://www.keyestudio.com/products/keyestudio

Open Arduino IDE and set serial port and baud rate.

Input AT to test communication. If it is successful, OK will be output.

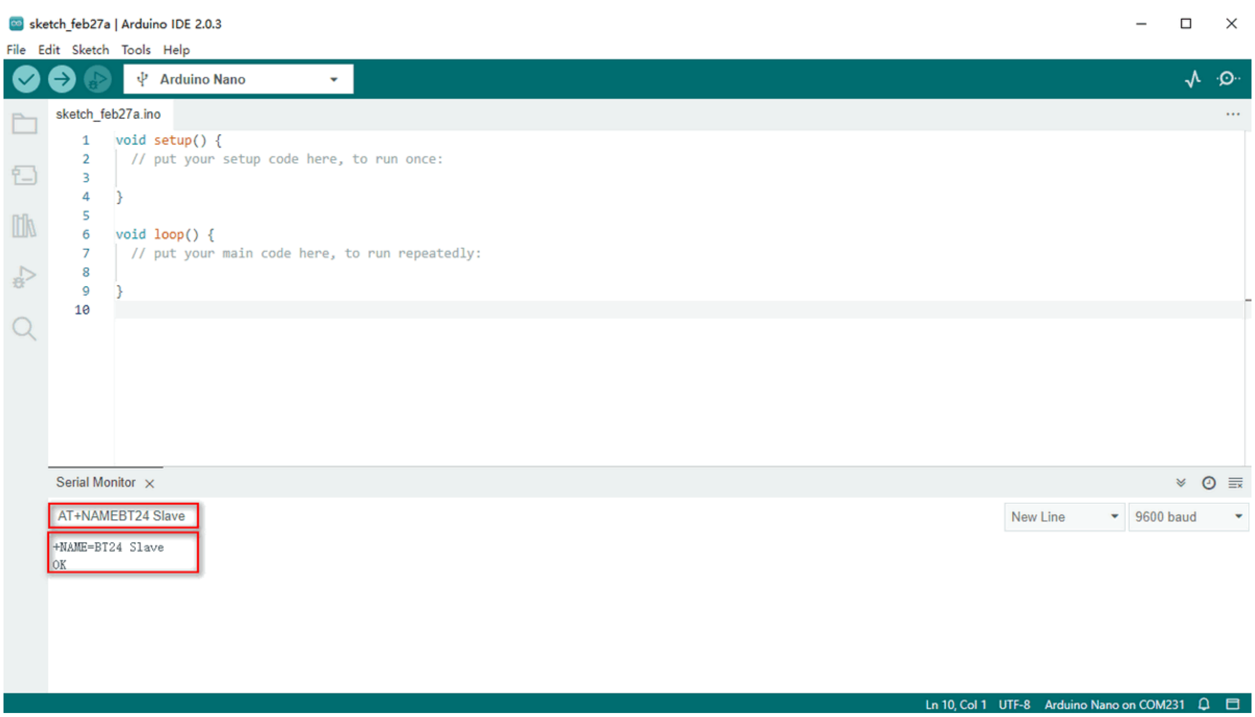


Query version number: Input AT+VERSION to output the version number .



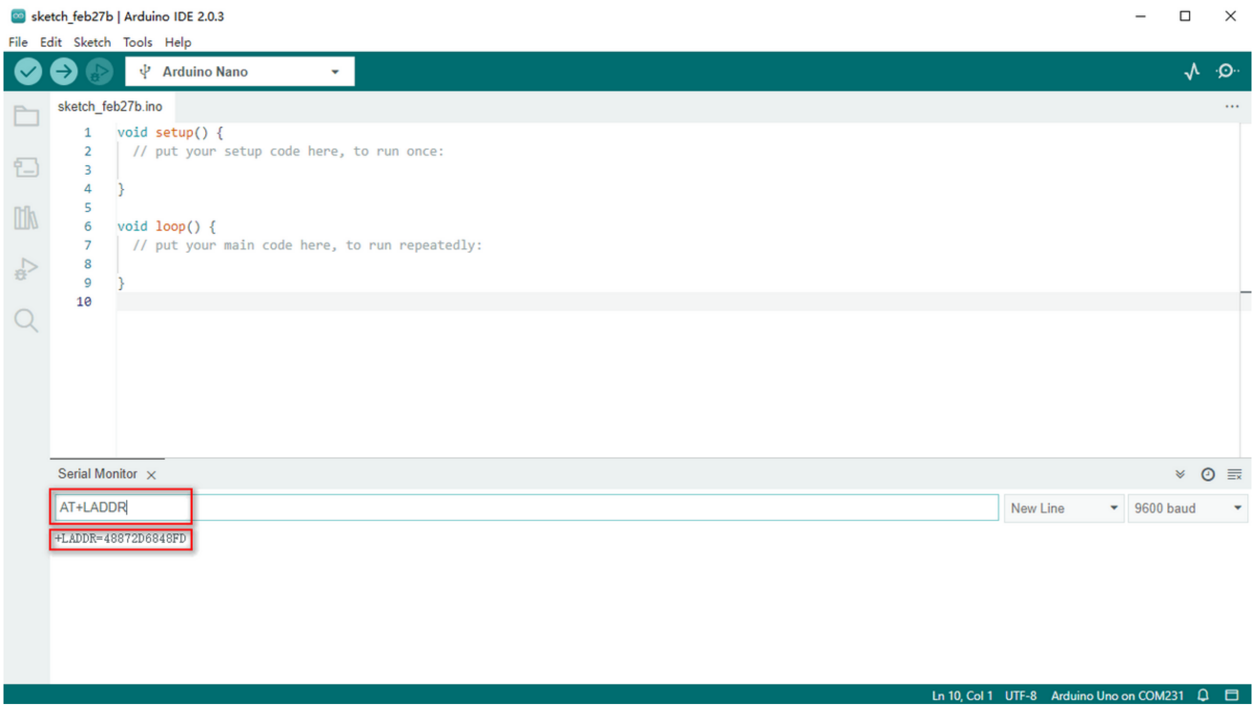
Query BT name: AT+NAME.

Revise BT name: Input AT+NAMEBT24 Slave to revise its name as BT24 Slave.



Query MAC address (an exclusive command for slave devices): Input AT+LADDR to show MAC address.

(Hosts connect to slave devices through MAC address.)



6.6.5 AT Command Collection

These commands apply to BT24 Bluetooth Module.

Keyestudio bt-24 Module RS232/TTL to UART:

https://www.keyestudio.com/search/?Keyword=bt-24

Note: Only hosts are privileged to visit and set MODE, and only slave devices are authorized to query address. After setting commands, you need to reset the Bluetooth module.

Commands for host devices:

NO.	Functions	Commands	Response	Description
1	Test Command	AT	OK	Test serial port
2	Query version number	AT+VER	+VERSION=<version>	<version > : Version numberIt varies from modules and customized demand.
3	Query MAC address	AT+LAD	+LADDR=<laddr>	<laddr> BT MAC address code
4	Query BT name	AT+NAM	+NAME=<name>	<name>: BT name, maximum of 28 bytes-Default name: BT24
5	Set BT name	AT+NAM	+NAME=<name>OK	
6	Query serial port stop bit	AT+STOI	+STOP=<param>	<param>: Serial number01 Stop bit12 Stop bitDefault value0
7	Set serial port stop bit	AT+STOI	+STOP=<param>OK	
8	Query-serial portcheck bit	AT+PARI	+PARI=<param>	<param>: Serial number0: None check 1: Odd check 2: Even check
9	Set serial port check bit	AT+PARI	+PARI=<param>OK	
10	Query baud rate	AT+BAU	+BAUD=<baud>	<baud>: Baud rate serial number1: 2400 5: 384002: 4800 6: 576003: 9600 7: 1152004: 19200Default value: 3 (9600)
11	Set baud rate	AT+BAU	+BAUD=<baud>OK	
12	Query searching mode	AT+MOD	+ MODE<Param>	<param>: (0123)0: Normal mode1: Manufacturer informationfilter mode 2: pairing mode3: IBEACON information obtaining modeDefault value0
13	Set searching mode	AT+MOD	+MODE<Parm>OK	
14	Disconnect	AT+DISC		
15	Reset	AT+RESI	+RESETOKPower On	
16	Restore factory settings	AT+DEF/	+DEFAULTOKPower On	
17	Query filtering signal intensity	AT+SCAI	+SCANRSSI<rssi>	<rssi>: signal intensity1-100 (decimal system)Default value: 100
18	Set filtering signal intensity	AT+SCAI	OK	
19	Query searching time	AT+TIMI	+TIMEINQ<time>	<time>: time(1-200) *100msDefault value: 10
20	Set	AT+TIMI	OK	

Error code:

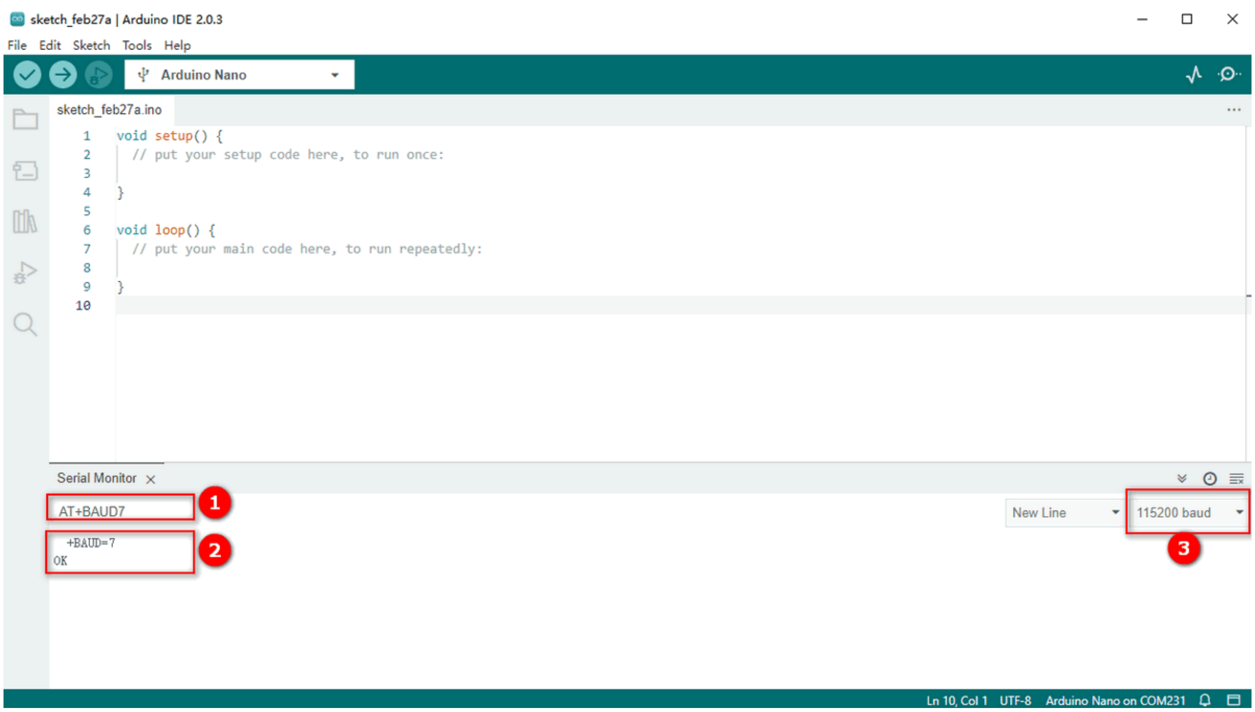
NO.	Error code	Error description
1	101	Parameter length error
2	102	Parameter format error
3	103	Abnormal parameter data
4	104	Command error

6.6.6 Connect Host to Slave Devices

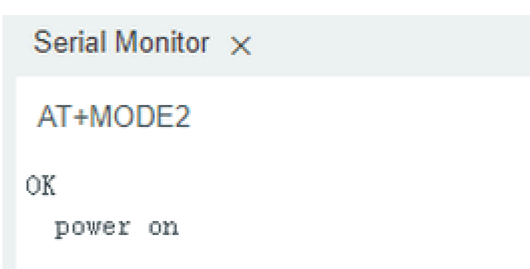
Upload AT command to pair host with slave device. The two Bluetooth will connect automatically after being set and powering on.

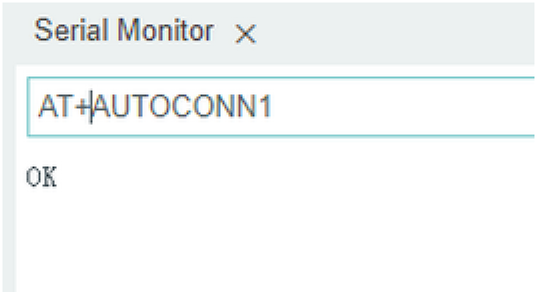
Step 1. Set baud rate of the host and slave to the same as AT command (Set host first, and here we set baud rate to 115200). Press RESET button.

Command 1: **AT+BAUD7** Command 2: **AT+RESET**

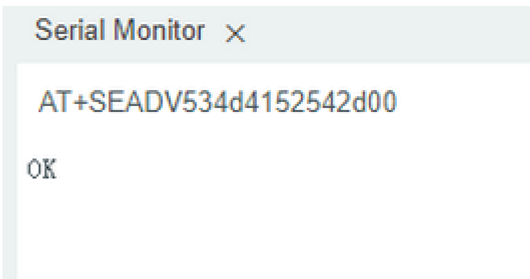


Step 2. Set host mode to MODE 2. Send AT+MODE and AT+AUTOCONN1.





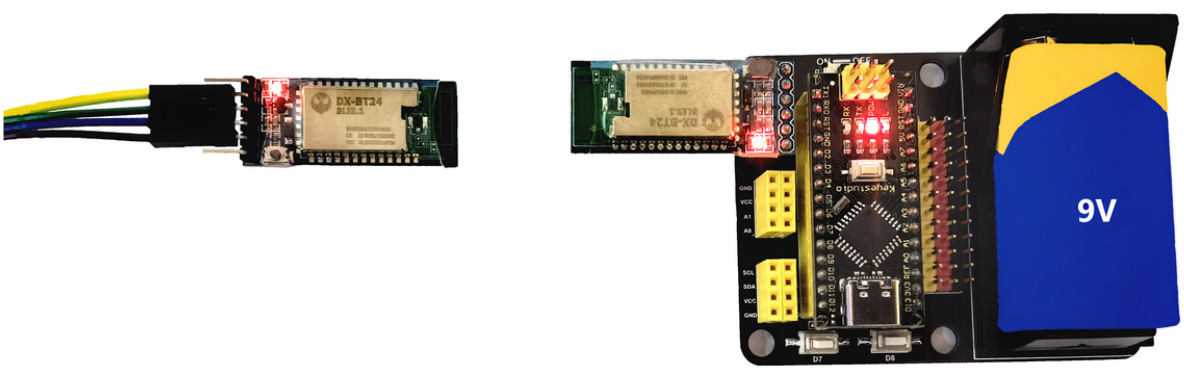
Step 3. Input AT+SEADV534d4152542d00 to enter slave pairing mode. Input AT+CLEARADV to exit.



Step 4. Power up two modules, and the host binds itself to the address code of the slave, and it will keep connection even in an outage.

Send AT+CLEAR or press a certain button to remove binding.

After connection, LED on the host will light up, while that on the slave will blink per 3s.



6.6.7 Communication of Host and Slave Device

Step 1. Install host Bluetooth on the expansion board, and burn the test code on Arduino NANO. Note: Please keep the Bluetooth disconnected when uploading code.

Please refer to the folder lesson_3_1.

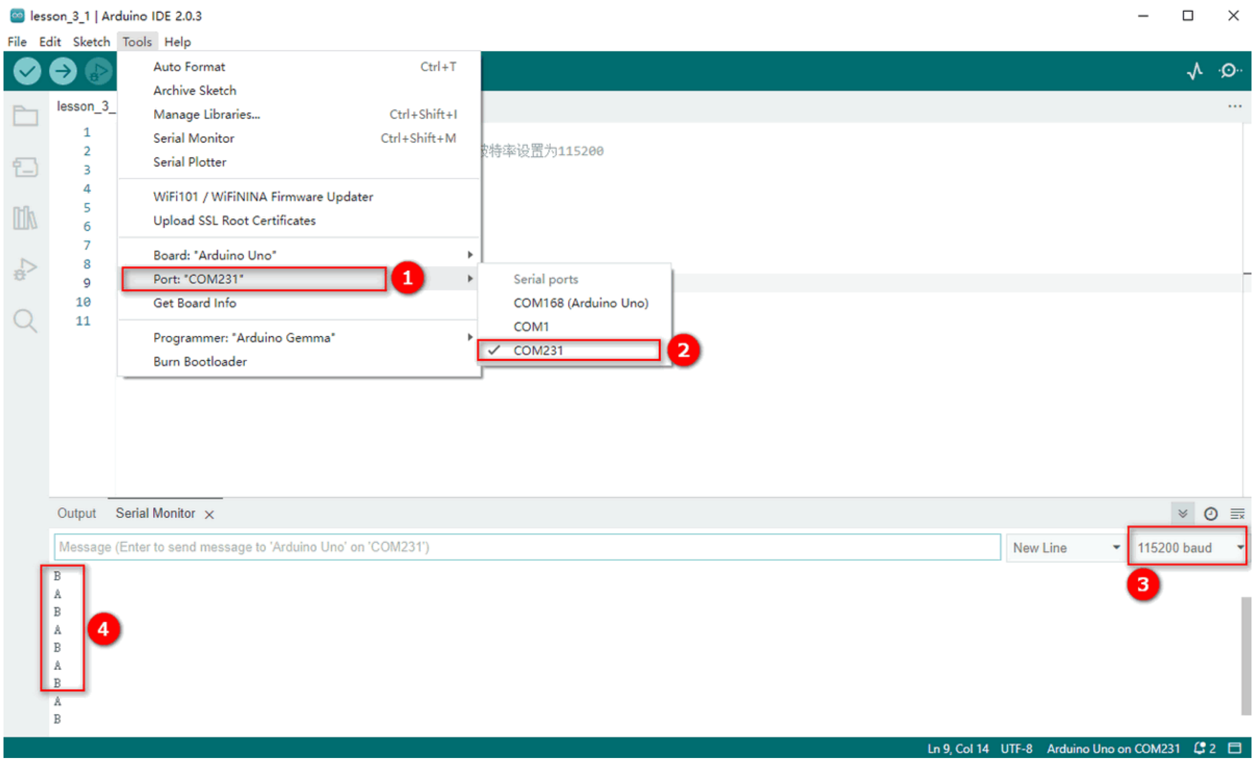
Code:

[lesson_3_1.ino]:

```
void setup() {

Serial.begin(115200);// Set baud rate to 115200 and initialize the serial port

}

void loop() {

Serial.println("A");

delay(500);

Serial.println("B");

delay(500);

}
```

Step 2.

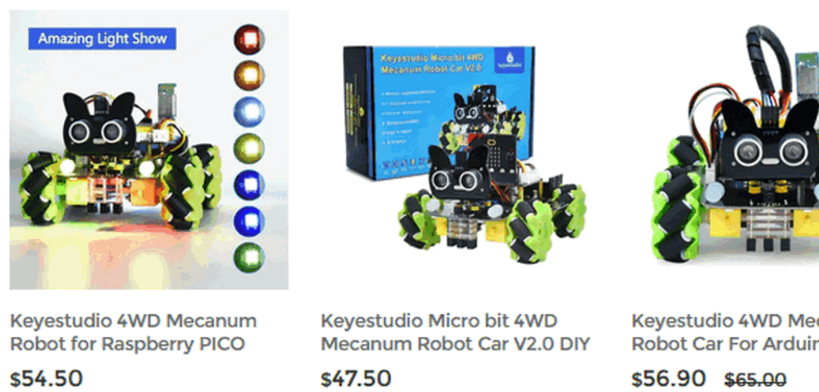
Connect Bluetooth with computer via USB-to-serial port module. Select the serial number and set baud rate to 115200, and the slave receives messages and serial port alternately prints“A”and“B”per 0.5s.



6.7 Operate Mecanum Cars

Operate the movement of the car by gestures.

Mecanum cars:

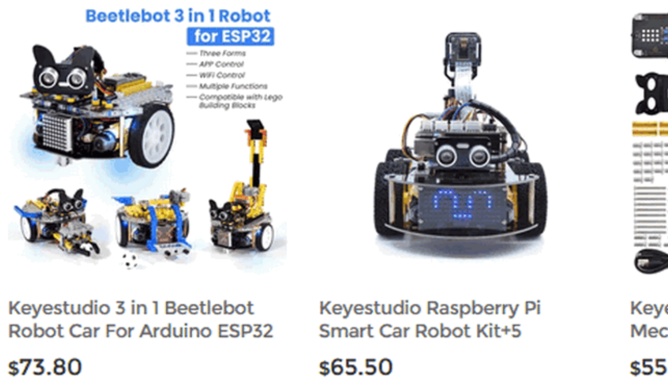


https://www.keyestudio.com/search/?Keyword=mecanum

This glove controls not only Mecanum cars but also mini tanks, smart homing cars and Beetlebot cars.

Other mini cars:

https://www.keyestudio.com/search/?&Keyword=car&Sort=4d&page=1



6.7.1 Angles of the Glove

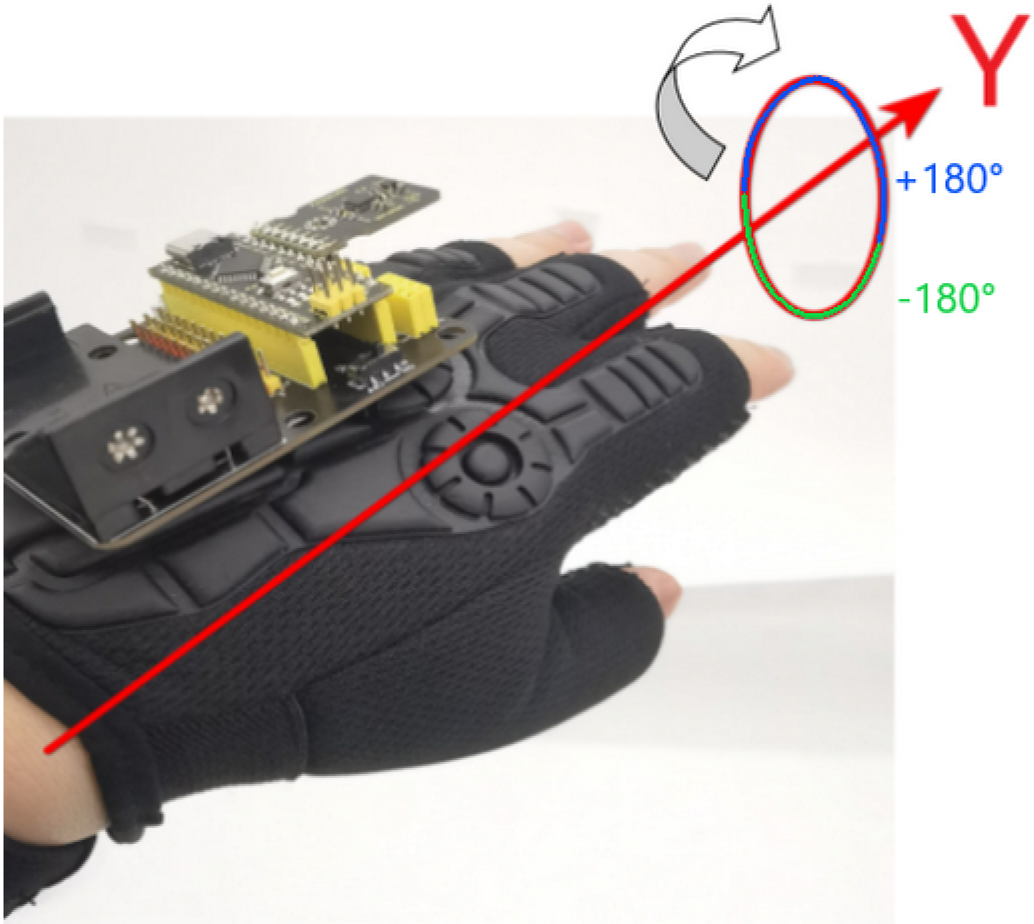
A null shift may occur on Yaw if the glove only equipped with MPU6050, hence we only snatch the data of Roll and Pitch. If you need full data, please install a magnetometer for calibration.

Y-axis: Fingers face forward and the palm rolls from side to side.

0°: Stay your hand still.

- 180°: Roll down your hand to the left.

+180°: Roll down your hand to the right.

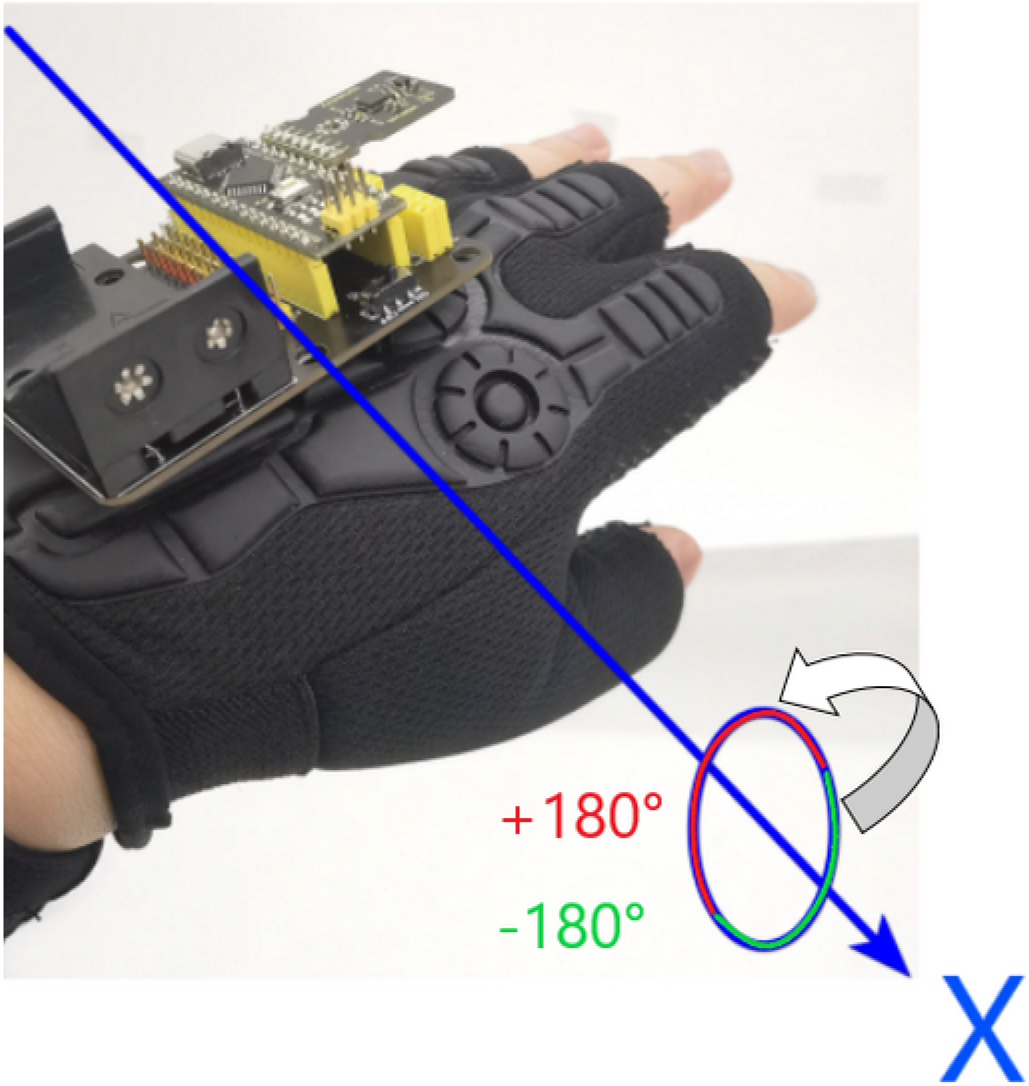


X-axis: Fingers face forward and the hand moves up and down centered as the palm.

0°: Stay your hand still.

- 180°: Move upwards your hand.

+180°: Move downwards your hand.



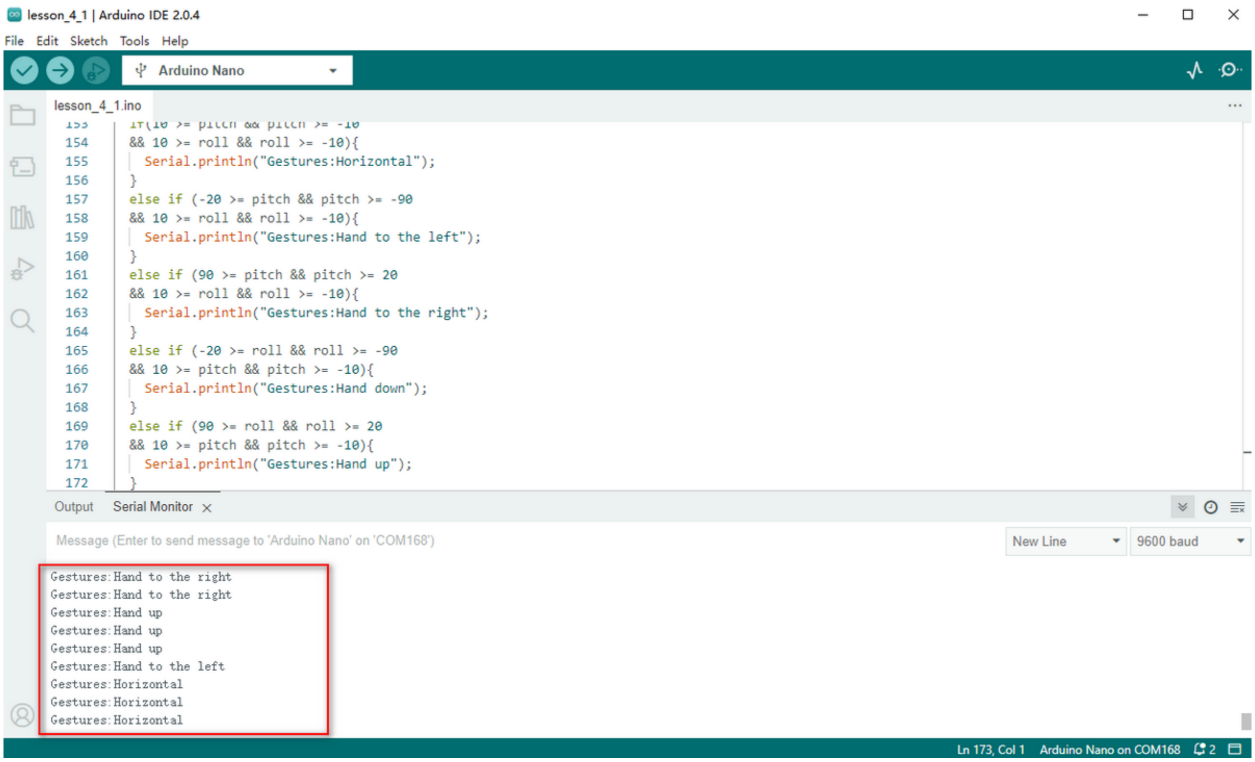
6.7.2 Gesture Angle Code

Set a range of gesture angles as follows (or at your will). When your gesture reaches the range, the mini car preforms specific actions.

1. Remain horizontal: -10°~10° in axis X and axis Y
2. Roll left: -20~-90° in axis Y
3. Roll right: 20~90° in axis Y
4. Hold upwards: 20~90° in axis X
5. Hold downwards: -20~-90° in axis X

Note: Please keep the Bluetooth disconnected when uploading code.

Open serial port after burning the code, and the gesture data is displayed.



Code:

[lesson_4_1.ino]:

```
#include "MPU6050.h"

MPU6050lib mpu;



float aRes, gRes;         // scale resolutions per LSB for the sensors

int16_t accelCount[3];      // Stores the 16-bit signed accelerometer sensor output

int16_t gyroCount[3];      // Stores the 16-bit signed gyro sensor output

float ax, ay, az;         // Stores the real accel value in g's

float gyrox, gyroy, gyroz;    // Stores the real gyro value in degrees per seconds

float gyroBias[3] = {0, 0, 0};

float accelBias[3] = {0, 0, 0}; // Bias corrections for gyro and accelerometer

int16_t tempCount;         // Stores the real internal chip temperature in degrees Celsius

float temperature;

float SelfTest[6];
```

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```
float q[4] = {1.0f, 0.0f, 0.0f, 0.0f};// vector to hold quaternion

float pitch, yaw, roll;

// parameters for 6 DoF sensor fusion calculations

float GyroMeasError = PI * (40.0f / 180.0f);    //gyroscope measurement error in rads/s␣
↪(start at 60 deg/s), then reduce after ~10 s to 3

float beta = sqrt(3.0f / 4.0f) * GyroMeasError;  // compute beta()

float GyroMeasDrift = PI * (2.0f / 180.0f);    // gyroscope measurement drift in rad/s/s␣
↪(start at 0.0 deg/s/s)

float zeta = sqrt(3.0f / 4.0f) * GyroMeasDrift;  // compute zeta, the other free␣
↪parameter in the Madgwick scheme usually set to a small or zero value

float deltat = 0.0f;                // integration interval for both filter schemes

uint32_t lastUpdate = 0, firstUpdate = 0;     // used to calculate integration interval

uint32_t Now = 0;                   // used to calculate integration interval



void setup()

{

 Wire.begin();

 Serial.begin(9600);



 // Read the WHO_AM_I register, this is a good test of communication

 uint8_t c = mpu.readByte(MPU6050_ADDRESS, WHO_AM_I_MPU6050); // Read WHO_AM_I register␣
↪for MPU-6050

 Serial.print("I AM ");

 Serial.println(c, HEX);



 mpu.settings(AFS_8G, GFS_250DPS);

 if (c == 0x68) //WHO_AM_I should always be 0x68

 {
```

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```
Serial.println("MPU6050 is online...");

// Start by performing self test and reporting values

mpu.MPU6050SelfTest(SelfTest);

Serial.print("x-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[0],1); Serial.println("% of factory value");

Serial.print("y-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[1],1); Serial.println("% of factory value");

Serial.print("z-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[2],1); Serial.println("% of factory value");

Serial.print("x-axis self test: gyration trim within : "); Serial.print(SelfTest[3],1);
↪ Serial.println("% of factory value");

Serial.print("y-axis self test: gyration trim within : "); Serial.print(SelfTest[4],1);
↪ Serial.println("% of factory value");

Serial.print("z-axis self test: gyration trim within : "); Serial.print(SelfTest[5],1);
↪ Serial.println("% of factory value");



if (SelfTest[0] < 1.0f && SelfTest[1] < 1.0f && SelfTest[2] < 1.0f && SelfTest[3] < 1.
↪0f && SelfTest[4] < 1.0f && SelfTest[5] < 1.0f) {

 Serial.println("Pass Selftest!");

 // Calibrate gyro and accelerometers, load biases in bias registers

 mpu.calibrateMPU6050(gyroBias, accelBias);

 Serial.println("MPU6050 bias");

 Serial.println(" x\t  y\t  z  ");

 Serial.print((int)(1000 * accelBias[0])); Serial.print('\t');

 Serial.print((int)(1000 * accelBias[1])); Serial.print('\t');

 Serial.print((int)(1000 * accelBias[2]));

 Serial.println(" mg");



 Serial.print(gyroBias[0], 1); Serial.print('\t');

 Serial.print(gyroBias[1], 1); Serial.print('\t');
```

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```
   Serial.print(gyroBias[2], 1);

   Serial.println(" o/s");



   mpu.settings(AFS_2G, GFS_250DPS);

   mpu.initMPU6050();

   // Initialize device for active mode read of accelerometer , gyroscope, and␣
↪temperature

   Serial.println("MPU6050 initialized for active data mode....");

  }

 }

 else

 {

  Serial.print("Could not connect to MPU6050: 0x");

  Serial.println(c, HEX);

  while(1); // Loop forever if communication doesn't happen

 }

}



void loop()

{

 // If data ready bit set, all data registers have new data

 if (mpu.readByte(MPU6050_ADDRESS, INT_STATUS) & 0x01) { // check if data ready interrupt

  mpu.readAccelData(accelCount);   // Read the x/y/z adc values

  aRes = mpu.getAres();       // Acquire the converted value



  // Now we'll calculate the accleration value into actual g's
```

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```
  ax = (float)accelCount[0] * aRes; // get actual g value, this depends on scale being␣
↪set

  ay = (float)accelCount[1] * aRes;

  az = (float)accelCount[2] * aRes;



  mpu.readGyroData(gyroCount);    // Read the x/y/z adc values

  gRes = mpu.getGres();       // Acquire the converted value



  // Calculate the gyro value into actual degrees per second

  gyrox = (float)gyroCount[0] * gRes; // get actual gyro value, this depends on scale␣
↪being set

  gyroy = (float)gyroCount[1] * gRes;

  gyroz = (float)gyroCount[2] * gRes;



  tempCount = mpu.readTempData(); // Read the x/y/z adc values

  temperature = ((float) tempCount) / 340. + 36.53; // Temperature in degrees Centigrade

 }

 // Acquire the current time of the system in ms

 Now = micros();

 // set integration time by time elapsed since last filter update

 deltat = ((Now - lastUpdate) / 1000000.0f);

 lastUpdate = Now;

 if(lastUpdate - firstUpdate > 10000000uL) {

  beta = 0.041; // decrease filter gain after stabilized

  zeta = 0.015; // increase gyro bias drift gain after stabilized

 }

 // Convert the gyroscope data to radians

```

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```
gyrox = gyrox  * PI / 180.0f;

gyroy = gyroy * PI / 180.0f;

gyroz = gyroz * PI / 180.0f;

// Quaternion conversion function

MadgwickQuaternionUpdate(ax, ay, az, gyrox, gyroy, gyroz);



// Define output variables from updated quaternion---these are Tait-Bryan angles,␣
↪commonly used in aircraft orientation.

// In this coordinate system, the positive z-axis is down toward Earth.

// Yaw is the angle between Sensor x-axis and Earth magnetic North (or true North if␣
↪corrected for local declination, looking down on the sensor positive yaw is␣
↪counterclockwise.

// Pitch is angle between sensor x-axis and Earth ground plane, toward the Earth is␣
↪positive, up toward the sky is negative.

// Roll is angle between sensor y-axis and Earth ground plane, y-axis up is positive␣
↪roll.

// These arise from the definition of the homogeneous rotation matrix constructed from␣
↪quaternions.

// Tait-Bryan angles as well as Euler angles are non-commutative; that is, the get the␣
↪correct orientation the rotations must be

// applied in the correct order which for this configuration is yaw, pitch, and then␣
↪roll.

yaw  = atan2(2.0f * (q[1] * q[2] + q[0] * q[3]), q[0] * q[0] + q[1] * q[1] - q[2] *␣
↪q[2] - q[3] * q[3]);

pitch = -asin(2.0f * (q[1] * q[3] - q[0] * q[2]));

roll  = atan2(2.0f * (q[0] * q[1] + q[2] * q[3]), q[0] * q[0] - q[1] * q[1] - q[2] *␣
↪q[2] + q[3] * q[3]);



pitch *= 180.0f / PI;

yaw  *= 180.0f / PI;

roll  *= 180.0f / PI;
```

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```
 if(40 >= pitch && pitch >= -40

 && 40 >= roll && roll >= -40){

  Serial.println("Gestures:Horizontal");

 }

 else if (-40 >= pitch && pitch >= -90

 && 40 >= roll && roll >= -40){

  Serial.println("Gestures:Hand to the left");

 }

 else if (90 >= pitch && pitch >= 40

 && 40 >= roll && roll >= -40){

  Serial.println("Gestures:Hand to the right");

 }

 else if (-40 >= roll && roll >= -90

 && 40 >= pitch && pitch >= -40){

  Serial.println("Gestures:Hand down");

 }

 else if (90 >= roll && roll >= 20

 && 40 >= pitch && pitch >= -40){

  Serial.println("Gestures:Hand up");

 }


 delay(100);

}
// Implementation of Sebastian Madgwick's "...efficient orientation filter for...␣
↪inertial/magnetic sensor arrays"

// which fuses acceleration and rotation rate to produce a quaternion-based estimate of␣
↪relative
```

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```
// device orientation -- which can be converted to yaw, pitch, and roll. Useful for␣
↪stabilizing quadcopters, etc.

// The performance of the orientation filter is at least as good as conventional Kalman-
↪based filtering algorithms

// but is much less computationally intensive---it can be performed on a 3.3 V Pro Mini␣
↪operating at 8 MHz!

void MadgwickQuaternionUpdate(float ax, float ay, float az, float gyrox, float gyroy,␣
↪float gyroz)

{

 float q1 = q[0], q2 = q[1], q3 = q[2], q4 = q[3];     // short name local variable for␣
↪readability

 float norm;                              //vector norm

 float f1, f2, f3;                           // objective funcyion elements

 float J_11or24, J_12or23, J_13or22, J_14or21, J_32, J_33; // objective function Jacobian

 float qDot1, qDot2, qDot3, qDot4;

 float hatDot1, hatDot2, hatDot3, hatDot4;

 float gerrx, gerry, gerrz, gbiasx, gbiasy, gbiasz;     // gyro bias error



 // Auxiliary variables to avoid repeated arithmetic

 float _halfq1 = 0.5f * q1;

 float _halfq2 = 0.5f * q2;

 float _halfq3 = 0.5f * q3;

 float _halfq4 = 0.5f * q4;

 float _2q1 = 2.0f * q1;

 float _2q2 = 2.0f * q2;

 float _2q3 = 2.0f * q3;

 float _2q4 = 2.0f * q4;

 float _2q1q3 = 2.0f * q1 * q3;
```

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```
float _2q3q4 = 2.0f * q3 * q4;


// Normalise accelerometer measurement

norm = sqrt(ax * ax + ay * ay + az * az);

if (norm == 0.0f) return; // handle NaN

norm = 1.0f/norm;

ax *= norm;

ay *= norm;

az *= norm;


// Compute the objective function and Jacobian

f1 = _2q2 * q4 - _2q1 * q3 - ax;

f2 = _2q1 * q2 + _2q3 * q4 - ay;

f3 = 1.0f - _2q2 * q2 - _2q3 * q3 - az;

J_11or24 = _2q3;

J_12or23 = _2q4;

J_13or22 = _2q1;

J_14or21 = _2q2;

J_32 = 2.0f * J_14or21;

J_33 = 2.0f * J_11or24;


// Compute the gradient (matrix multiplication)

hatDot1 = J_14or21 * f2 - J_11or24 * f1;

hatDot2 = J_12or23 * f1 + J_13or22 * f2 - J_32 * f3;

hatDot3 = J_12or23 * f2 - J_33 *f3 - J_13or22 * f1;

hatDot4 = J_14or21 * f1 + J_11or24 * f2;
```

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```
// Normalize the gradient
norm = sqrt(hatDot1 * hatDot1 + hatDot2 * hatDot2 + hatDot3 * hatDot3 + hatDot4 *␣
↪hatDot4);
hatDot1 /= norm;
hatDot2 /= norm;
hatDot3 /= norm;
hatDot4 /= norm;

// Compute estimated gyroscope biases
gerrx = _2q1 * hatDot2 - _2q2 * hatDot1 - _2q3 * hatDot4 + _2q4 * hatDot3;
gerry = _2q1 * hatDot3 + _2q2 * hatDot4 - _2q3 * hatDot1 - _2q4 * hatDot2;
gerrz = _2q1 * hatDot4 - _2q2 * hatDot3 + _2q3 * hatDot2 - _2q4 * hatDot1;

// Compute and remove gyroscope biases
gbiasx += gerrx * deltat * zeta;
gbiasy += gerry * deltat * zeta;
gbiasz += gerrz * deltat * zeta;
gyrox -= gbiasx;
gyroy -= gbiasy;
gyroz -= gbiasz;

// Compute the quaternion derivative
qDot1 = -_halfq2 * gyrox - _halfq3 * gyroy - _halfq4 * gyroz;
qDot2 =  _halfq1 * gyrox + _halfq3 * gyroz - _halfq4 * gyroy;
qDot3 =  _halfq1 * gyroy - _halfq2 * gyroz + _halfq4 * gyrox;
qDot4 =  _halfq1 * gyroz + _halfq2 * gyroy - _halfq3 * gyrox;
```

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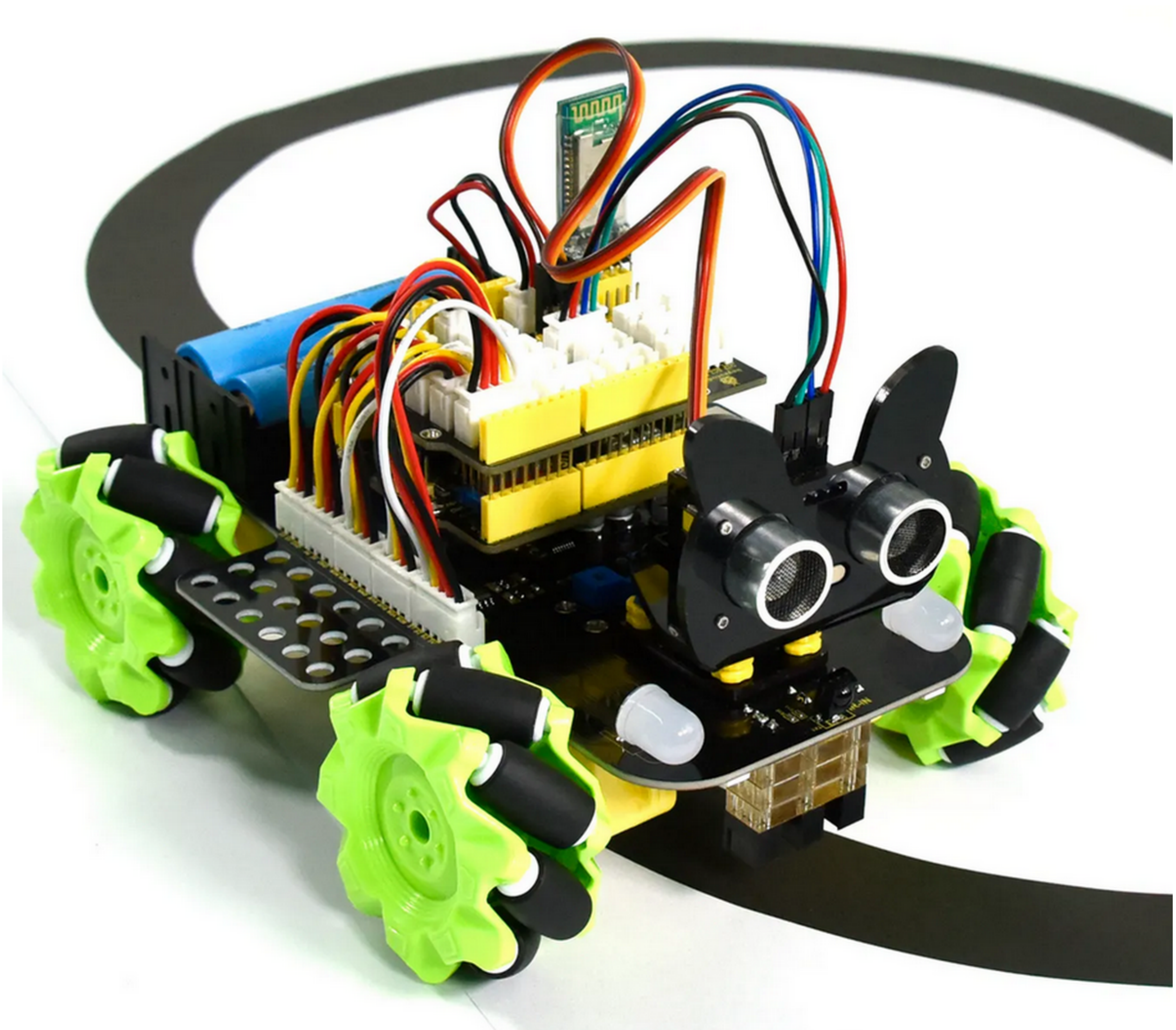
```
  // Compute then integrate estimated quaternion derivative
  q1 += (qDot1 -(beta * hatDot1)) * deltat;
  q2 += (qDot2 -(beta * hatDot2)) * deltat;
  q3 += (qDot3 -(beta * hatDot3)) * deltat;
  q4 += (qDot4 -(beta * hatDot4)) * deltat;

  // Normalize the quaternion
  norm = sqrt(q1 * q1 + q2 * q2 + q3 * q3 + q4 * q4);    //  normalise quaternion
  norm = 1.0f/norm;
  q[0] = q1 * norm;
  q[1] = q2 * norm;
  q[2] = q3 * norm;
  q[3] = q4 * norm;
}
```

6.7.3 Car Operation Code

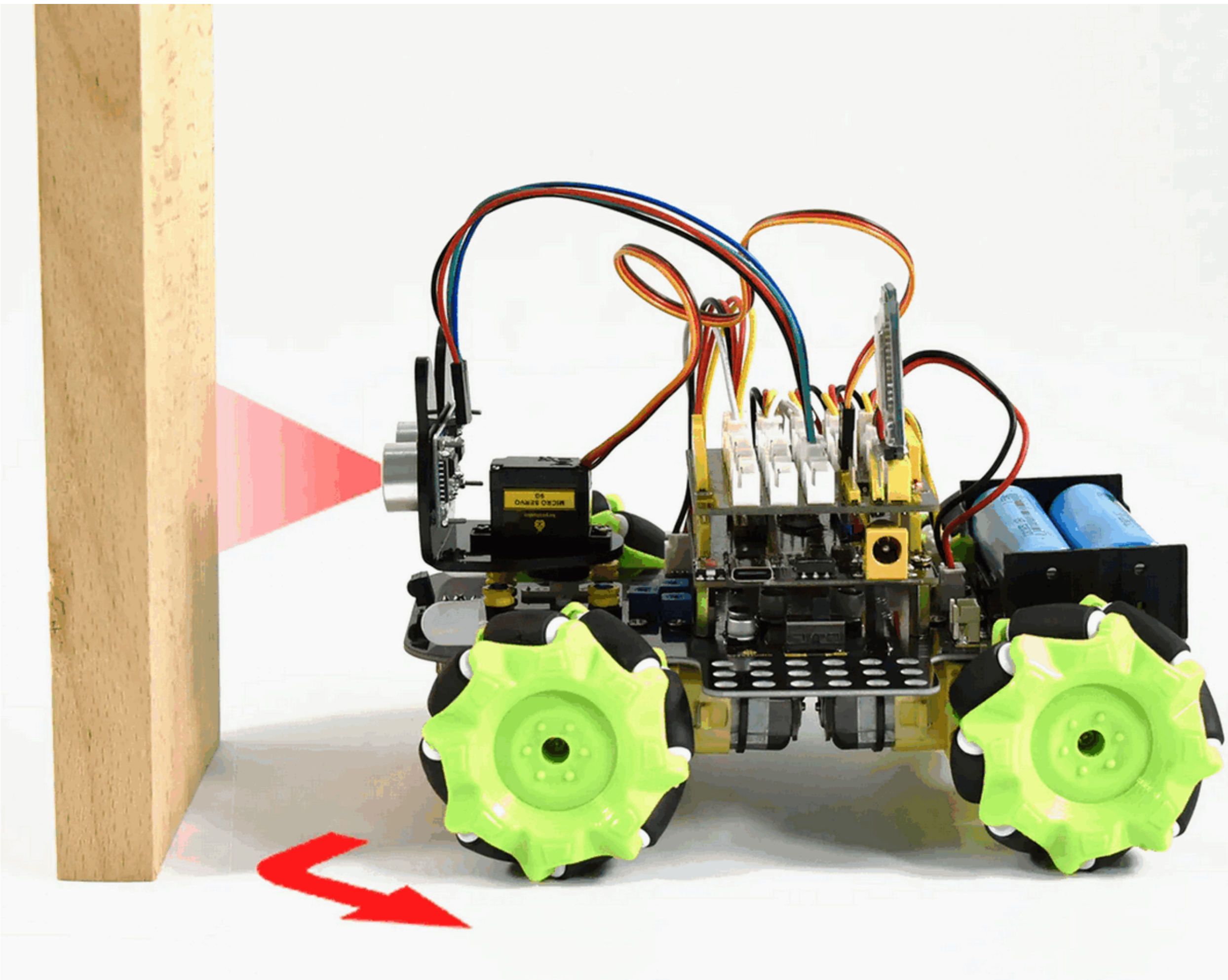
Mecanum Cars support omnidirectional movements, including forward, transverse, oblique, rotary and even their combination.



Mecanum Cars: https://www.keyestudio.com/search/?Keyword=mecanum

---

Four wheels have their private motors, so that the car is flexible in its multi-directional movements.



Pair the glove with Bluetooth on the car. Connect host and slave Bluetooth by AT commands (the glove is the host, and the car is the slave).

AT commands for the host:

- AT command 1: *AT+BAUD7* : Set the baud rate to 115200 (You can set other baud rate).
- AT command 2: *AT+RESET* : Reset the Bluetooth.
- AT command 3: *AT+RESET* : Set to MODE 2 for pairing.
- AT command 4: *AT+AUTOCONN1* : Automatically connect when powering up.

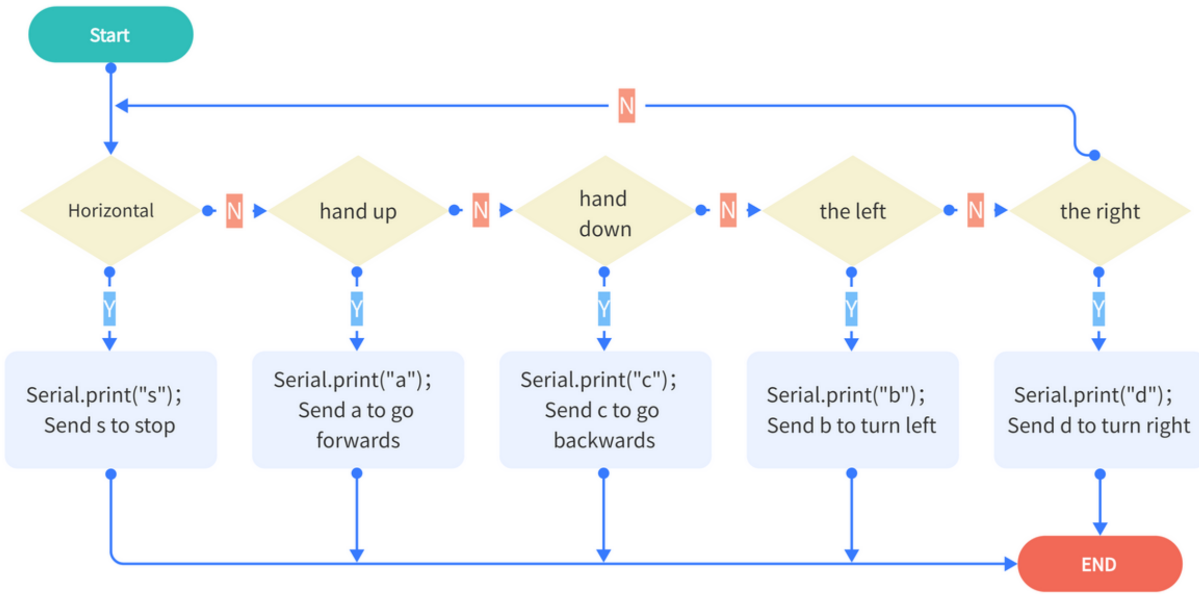
AT commands for the slave:

- AT command 1*AT+SEADV534d4152542d00* : Set the slave device to Pairing Mode, and it connects automatically when powering on.

Define the corresponding functions of different gestures.

Two buttons are reserved on the expansion board, which are used to alter the function control of the mini car.

Flow chart



Host device definitions:

(You may set angles and functions according to your own needs.)

Gesture One:

Gestures	Euler Angle	Functions
40~60° hand up	-40°pitch-60°	Serial.print("a"); //Send a to go forwards
40~60° hand down	40°pitch60°	Serial.print("c"); //Send c to go backwards
40~60° to the left	-40°roll-60°	Serial.print("b"); //Send b to turn left
40~60° to the right	40°roll60°	Serial.print("d"); //Send d to turn right
Horizontal	40°pitch-40°40°roll-40°	Serial.print("s"); //Send s to stop

Gesture Two:

Gestures	Euler Angle	Functions
60~120° hand up	-60°pitch-120°	Serial.print("f");//Send f to drift left
60~120° hand down	60°pitch120°	Serial.print("e");//Send e to drift right
60~120° to the left	-60°roll-120°	Serial.print("k");//Send k to move left
60~120° to the right	60°roll120°	Serial.print("h");//Send h to move right

Gesture Three:

- Press D7 to light the colorful LED and press again to turn it off.
  - Code: Serial.print("t")// Light on

        * Code: Serial.print("u")// Light off

- Press D8 to light the RGB LED and press again to douse it.
    - Code: Serial.print("m")// Light on
        * Code: Serial.print("o")// Light off

Slave device interfaces:

(You may set interface functions according to your own needs.)

Received Commands	Functions
s	Stop
a	Go forwards
c	Go backwards
b	Turn left
d	Turn right
k	Move left
h	Move right
l	Move up-left
j	Move down-left
g	Move up-right
i	Move down-right
e	Drift right
f	Drift left
p	Track
q	Follow
r	Avoid obstacle
t	Turn on the colorful LED
u	Turn off the colorful LED
m	Turn on the 2812 light
o	Turn off the 2812 light
n	Toggle the color of 2812 light
x+0~255	Set speed of motor M1
v+0~255	Set speed of motor M2
w+0~255	Set speed of motor M3
y+0~255	Set speed of motor M4

Please refer to the folder lesson_4_2.

Code:

[lesson_4_2.ino]:

```
#include "Wire.h"

#include "MPU6050.h"



MPU6050lib mpu;


```

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```
float aRes, gRes;        // scale resolutions per LSB for the sensors

int16_t accelCount[3];      // Stores the 16-bit signed accelerometer sensor output

int16_t gyroCount[3];      // Stores the 16-bit signed gyro sensor output

float SelfTest[6];

float gyroBias[3] = {0, 0, 0};

float accelBias[3] = {0, 0, 0}; // Bias corrections for gyro and accelerometer

float q[4] = {1.0f, 0.0f, 0.0f, 0.0f};// vector to hold quaternion

float pitch, yaw, roll;

// parameters for 6 DoF sensor fusion calculations

float GyroMeasError = PI * (40.0f / 180.0f);    // gyroscope measurement error in rads/s␣
↪(start at 60 deg/s), then reduce after ~10 s to 3

float beta = sqrt(3.0f / 4.0f) * GyroMeasError;  // compute beta()

float GyroMeasDrift = PI * (2.0f / 180.0f);    // gyroscope measurement drift in rad/s/s␣
↪(start at 0.0 deg/s/s)

float zeta = sqrt(3.0f / 4.0f) * GyroMeasDrift;  // compute zeta, the other free␣
↪parameter in the Madgwick scheme usually set to a small or zero value

float deltat = 0.0f;                // integration interval for both filter schemes

uint32_t lastUpdate = 0, firstUpdate = 0;     // used to calculate integration interval

uint32_t Now = 0;                 // used to calculate integration interval

double ax,ay,az; // Output of the filter

double gyrox,gyroy,gyroz; // Output of the filter

int btnA = 7; // Define two buttons

int btnB = 8;

int btnAv = 0;  // Acquire the two button values

int btnBv = 0;



void setup()
```

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```
{

 Wire.begin();

 Serial.begin(115200);



 uint8_t c = mpu.readByte(MPU6050_ADDRESS, WHO_AM_I_MPU6050);  // Read WHO_AM_I register␣
↪for MPU-6050

 Serial.print("I AM ");

 Serial.println(c, HEX);

 mpu.settings(AFS_8G, GFS_250DPS);

 if (c == 0x68) // WHO_AM_I should always be 0x68

 {

  Serial.println("MPU6050 is online...");

  // Start by performing self test and reporting values

  mpu.MPU6050SelfTest(SelfTest);

  Serial.print("x-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[0],1); Serial.println("% of factory value");

  Serial.print("y-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[1],1); Serial.println("% of factory value");

  Serial.print("z-axis self test: acceleration trim within : "); Serial.
↪print(SelfTest[2],1); Serial.println("% of factory value");

  Serial.print("x-axis self test: gyration trim within : "); Serial.print(SelfTest[3],1);
↪ Serial.println("% of factory value");

  Serial.print("y-axis self test: gyration trim within : "); Serial.print(SelfTest[4],1);
↪ Serial.println("% of factory value");

  Serial.print("z-axis self test: gyration trim within : "); Serial.print(SelfTest[5],1);
↪ Serial.println("% of factory value");



  if (SelfTest[0] < 1.0f && SelfTest[1] < 1.0f && SelfTest[2] < 1.0f && SelfTest[3] < 1.
↪0f && SelfTest[4] < 1.0f && SelfTest[5] < 1.0f) {

   Serial.println("Pass Selftest!");

```

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```
    // Calibrate gyro and accelerometers, load biases in bias registers

    mpu.calibrateMPU6050(gyroBias, accelBias);

    Serial.println("MPU6050 bias");

    Serial.println(" x\t  y\t  z  ");

    Serial.print((int)(1000 * accelBias[0])); Serial.print('\t');

    Serial.print((int)(1000 * accelBias[1])); Serial.print('\t');

    Serial.print((int)(1000 * accelBias[2]));

    Serial.println(" mg");



    Serial.print(gyroBias[0], 1); Serial.print('\t');

    Serial.print(gyroBias[1], 1); Serial.print('\t');

    Serial.print(gyroBias[2], 1);

    Serial.println(" o/s");



    mpu.settings(AFS_8G, GFS_2000DPS);

    mpu.initMPU6050();

    // Initialize device for active mode read of accelerometer , gyroscope, and␣
↪temperature

    Serial.println("MPU6050 initialized for active data mode....");

   }

  }

  else

  {

   Serial.print("Could not connect to MPU6050: 0x");

   Serial.println(c, HEX);

   while(1); // Loop forever if communication doesn't happen

  }
```

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```
 for(int i = 0; i < 300;i++){

  if (mpu.readByte(MPU6050_ADDRESS, INT_STATUS) & 0x01) { // check if data ready␣
↪interrupt

   mpu.readAccelData(accelCount);   // Read the x/y/z adc values

   mpu.readGyroData(gyroCount);    // Read the x/y/z adc values

  }

 }

}



void loop()

{

 // If data ready bit set, all data registers have new data

 if (mpu.readByte(MPU6050_ADDRESS, INT_STATUS) & 0x01) { // check if data ready interrupt

  mpu.readAccelData(accelCount);   // Read the x/y/z adc values

  // Kalman_Filter(accelCount[0],accelCount[1],accelCount[2]);

  // Now we'll calculate the accleration value into actual g's

  aRes = mpu.getAres();// Acquire the converted value

  ax = (float)accelCount[0] * aRes; // get actual g value, this depends on scale being␣
↪set

  ay = (float)accelCount[1] * aRes;

  az = (float)accelCount[2] * aRes;



  mpu.readGyroData(gyroCount);    // Read the x/y/z adc values

  // Kalman_Filter(gyroCount[0],gyroCount[1],gyroCount[2]);

  gRes = mpu.getGres();       //Acquire the converted value

  // Calculate the gyro value into actual degrees per second

  gyrox = (float)gyroCount[0] * gRes;// get actual gyro value, this depends on scale␣
```

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```
↪being set

  gyroy = (float)gyroCount[1] * gRes;

  gyroz = (float)gyroCount[2] * gRes;


 }

 // Acquire the current time of the system in ms

 Now = micros();

 // set integration time by time elapsed since last filter update

 deltat = ((Now - lastUpdate) / 1000000.0f);

 lastUpdate = Now;

 if(lastUpdate - firstUpdate > 10000000uL) {

  beta = 0.041; // decrease filter gain after stabilized

  zeta = 0.015; // increase gyro bias drift gain after stabilized

 }

 // Convert the gyro data to radians

 gyrox = gyrox  * PI / 180.0f;

 gyroy = gyroy * PI / 180.0f;

 gyroz = gyroz * PI / 180.0f;

 // Quaternion conversion function

 MadgwickQuaternionUpdate(ax, ay, az, gyrox, gyroy, gyroz);


 // yaw  = atan2(2.0f * (q[1] * q[2] + q[0] * q[3]), q[0] * q[0] + q[1] * q[1] - q[2] *␣
↪q[2] - q[3] * q[3]);

 pitch = -asin(2.0f * (q[1] * q[3] - q[0] * q[2]));

 roll  = atan2(2.0f * (q[0] * q[1] + q[2] * q[3]), q[0] * q[0] - q[1] * q[1] - q[2] *␣
↪q[2] + q[3] * q[3]);
```

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```
pitch *= 180.0f / PI;

yaw  *= 180.0f / PI;

roll  *= 180.0f / PI;


//Button A

if(!digitalRead(btnA))

{

 delay(100);

 if(!digitalRead(btnA))

 {

  btnAv = ~btnAv;

 }

}

//Button B

if(!digitalRead(btnB))

{

 delay(100);

 if(!digitalRead(btnB))

 {

  btnBv = ~btnBv;

 }

}

// Serial.print("roll:");Serial.println(roll);

// Serial.print("pitch:");Serial.println(pitch);


if(btnAv == -1) Serial.println("t");//light up the colorful LED
```

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```
else Serial.print("u");//turn on the colorful LED

if(btnBv == -1) Serial.println("m");// toggle the color of 2812

else Serial.print("o");//turn off the 2812


if(40 >= pitch && pitch >= -40

&& 40 >= roll && roll >= -40){

 Serial.print("s");//stop

}

else if (-40 >= pitch && pitch >= -60

&& 40 >= roll && roll >= -40){

 Serial.print("b");//turn left

}

else if(-60 >= pitch && pitch >= -120

&& 40 >= roll && roll >= -40){

 Serial.print("k");//move left

}

else if (60>= pitch && pitch >= 40

&& 40 >= roll && roll >= -40){

 Serial.print("d");//turn right

}

else if(120 >= pitch && pitch >= 60

&& 40 >= roll && roll >= -40){

 Serial.print("h");//move right

}

else if (-40 >= roll && roll >= -60

&& 40 >= pitch && pitch >= -40){
```

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```
  Serial.print("c");// go backwards

 }

 else if(-60 >= roll && roll >= -120

 && 40 >= pitch && pitch >= -40){

  Serial.print("f");//drift

 }

 else if (60 >= roll && roll >= 40

 && 40 >= pitch && pitch >= -40){

  Serial.print("a");//go forwards

 }

 else if(120 >= roll && roll >= 60

 && 40 >= pitch && pitch >= -40){

  Serial.print("e");//drift

 }

 delay(10);

}



// Implementation of Sebastian Madgwick's "...efficient orientation filter for...␣
↪inertial/magnetic sensor arrays"

// which fuses acceleration and rotation rate to produce a quaternion-based estimate of␣
↪relative

// device orientation -- which can be converted to yaw, pitch, and roll. Useful for␣
↪stabilizing quadcopters, etc.

// The performance of the orientation filter is at least as good as conventional Kalman-
↪based filtering algorithms

// but is much less computationally intensive---it can be performed on a 3.3 V Pro Mini␣
↪operating at 8 MHz!

void MadgwickQuaternionUpdate(float ax, float ay, float az, float gyrox, float gyroy,␣
↪float gyroz)
```

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```
{
 float q1 = q[0], q2 = q[1], q3 = q[2], q4 = q[3];     // short name local variable for␣
↪readability

 float norm;                         // vector norm

 float f1, f2, f3;                       // objective function elements

 float J_11or24, J_12or23, J_13or22, J_14or21, J_32, J_33; // objective function␣
↪Jacobian elements

 float qDot1, qDot2, qDot3, qDot4;

 float hatDot1, hatDot2, hatDot3, hatDot4;

 float gerrx, gerry, gerrz, gbiasx, gbiasy, gbiasz;     // gyro bias error



 // Auxiliary variables to avoid repeated arithmetic

 float _halfq1 = 0.5f * q1;

 float _halfq2 = 0.5f * q2;

 float _halfq3 = 0.5f * q3;

 float _halfq4 = 0.5f * q4;

 float _2q1 = 2.0f * q1;

 float _2q2 = 2.0f * q2;

 float _2q3 = 2.0f * q3;

 float _2q4 = 2.0f * q4;

 float _2q1q3 = 2.0f * q1 * q3;

 float _2q3q4 = 2.0f * q3 * q4;



 // Normalise accelerometer measurement

 norm = sqrt(ax * ax + ay * ay + az * az);

 if (norm == 0.0f) return; // handle NaN

 norm = 1.0f/norm;
```

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```
ax *= norm;

ay *= norm;

az *= norm;


// Compute the objective function and Jacobian

f1 = _2q2 * q4 - _2q1 * q3 - ax;

f2 = _2q1 * q2 + _2q3 * q4 - ay;

f3 = 1.0f - _2q2 * q2 - _2q3 * q3 - az;

J_11or24 = _2q3;

J_12or23 = _2q4;

J_13or22 = _2q1;

J_14or21 = _2q2;

J_32 = 2.0f * J_14or21;

J_33 = 2.0f * J_11or24;


// Compute the gradient (matrix multiplication)

hatDot1 = J_14or21 * f2 - J_11or24 * f1;

hatDot2 = J_12or23 * f1 + J_13or22 * f2 - J_32 * f3;

hatDot3 = J_12or23 * f2 - J_33 *f3 - J_13or22 * f1;

hatDot4 = J_14or21 * f1 + J_11or24 * f2;


// Normalize the gradient

norm = sqrt(hatDot1 * hatDot1 + hatDot2 * hatDot2 + hatDot3 * hatDot3 + hatDot4 *␣
↪hatDot4);

hatDot1 /= norm;

hatDot2 /= norm;

hatDot3 /= norm;
```

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```
hatDot4 /= norm;


// Compute estimated gyroscope biases

gerrx = _2q1 * hatDot2 - _2q2 * hatDot1 - _2q3 * hatDot4 + _2q4 * hatDot3;

gerry = _2q1 * hatDot3 + _2q2 * hatDot4 - _2q3 * hatDot1 - _2q4 * hatDot2;

gerrz = _2q1 * hatDot4 - _2q2 * hatDot3 + _2q3 * hatDot2 - _2q4 * hatDot1;


// Compute and remove gyroscope biases

gbiasx += gerrx * deltat * zeta;

gbiasy += gerry * deltat * zeta;

gbiasz += gerrz * deltat * zeta;

gyrox -= gbiasx;

gyroy -= gbiasy;

gyroz -= gbiasz;


// Compute the quaternion derivative

qDot1 = -_halfq2 * gyrox - _halfq3 * gyroy - _halfq4 * gyroz;

qDot2 =  _halfq1 * gyrox + _halfq3 * gyroz - _halfq4 * gyroy;

qDot3 =  _halfq1 * gyroy - _halfq2 * gyroz + _halfq4 * gyrox;

qDot4 =  _halfq1 * gyroz + _halfq2 * gyroy - _halfq3 * gyrox;


// Compute then integrate estimated quaternion derivative

q1 += (qDot1 -(beta * hatDot1)) * deltat;

q2 += (qDot2 -(beta * hatDot2)) * deltat;

q3 += (qDot3 -(beta * hatDot3)) * deltat;

q4 += (qDot4 -(beta * hatDot4)) * deltat;
```

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```
    // Normalize the quaternion
    norm = sqrt(q1 * q1 + q2 * q2 + q3 * q3 + q4 * q4);    // normalise quaternion
    norm = 1.0f/norm;
    q[0] = q1 * norm;
    q[1] = q2 * norm;
    q[2] = q3 * norm;
    q[3] = q4 * norm;
}
```

CHAPTER

SEVEN

FAQ

7.1 Q: What battery does NANO PLUS expansion board need?

A: 6F22 9V battery. Its dimentions are 26.5mm in thickness, 17.5mm in width and 48.5mm in height.

7.2 Q: An error occurs when burning programs on NANO PLUS mainboard.

A:

- Please check whether the USB serial port number is correct.
- Please check whether the board is correct.
- Please disconnect the Bluetooth when uploading code. Remember to install it after successfully uploading.

7.3 Q: The ID obtained by MPU6050 is 0XFF.

A: Please check whether MPU6050 is correctly installed on the expansion board.

7.4 Q: The Euler Angle obtained by MPU6050 is biased.

A: Please keep MPU6050 horizontal before acquiring data. Press the reset button and wait about 3s for initialization.

7.5 Q: Can other modules be installed on the expansion board?

A: Yes.

7.6 Q: NANO PLUS mainboard does not respond on startup, and the power indicator is off.

A: Please check the electricity of the 9V battery. Its normal operating voltage is 6~9V.

7.7 Q: Can the expansion board be connected to external power supply?

A: Yes. But connect 5V power only.

7.8 Q: No response after sending AT commands to the Bluetooth.

A:

- Please remain the baud rate consistent with the Bluetooth module. (Bluetooth initial baud rate: 9600)
- Please wire up correctly by DuPont wires according to the diagram.

CHAPTER

EIGHT

REFERENCE LINKS

Our official website:

https://www.keyestudio.com/

Mecanum cars

https://www.keyestudio.com/search/?Keyword=mecanum

USB-to-serial port module

https://www.keyestudio.com/search/?Keyword=ks0277

Slave Bluetooth

https://www.keyestudio.com/products/keyestudio

MPU6050 data sheet:

https://www.invensense.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf

https://www.invensense.com/wp-content/uploads/2015/02/MPU-6000-Register-Map1.pdf

Arduino official website:

https://www.arduino.cc/