TALKATIVE

Main Project Report

submitted by

Arjun M B (RET18AE018)
Mathew K Joshy (RET18AE037)
M K Arun (RET18AE039)

in partial fulfillment of the requirements
for the award of the degree of

Bachelor of Technology
in
Applied Electronics & Instrumentation Engineering

Rajagiri School of Engineering & Technology
Kochi, Kerala, India

APJ Abdul Kalam Technological University
Thiruvananthapuram, Kerala, India
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Rajagiri School of Engineering & Technology
Kochi, Kerala, India

Bonafide certificate

This is to certify that the main project report entitled **TALKATIVE** submitted by **Arjun M B (RET18AE018), Mathew K Joshy (RET18AE038)** and **M K Arun (RET18AE039)** in partial fulfillment of the requirements for the award of degree of **Bachelor of Technology** in **Applied Electronics & Instrumentation Engineering** is a bonafide record of the work carried out under our guidance and supervision at Rajagiri School of Engineering & Technology, Kochi, Kerala, India.

Ms.Priya S
Project Guide
Assistant Prof
Department of AEI
Rajagiri School of Engineering &
Technology, Kochi, Kerala, India

Dr. Hari C.V.
Head of the Department
Department of AEI
Rajagiri School of Engineering &
Technology.
Kochi, Kerala, India

Rajagiri School of Engineering & Technology
Department of Applied Electronics & Instrumentation Engineering

Institute Vision

To evolve into a premier technological and research institution, moulding eminent professionals with creative minds, innovative ideas and sound practical skill, and to shape a future where technology works for the enrichment of mankind.

Institute Mission

To impart state-of-the-art knowledge to individuals in various technological disciplines and to inculcate in them a high degree of social consciousness and human values, thereby enabling them to face the challenges of life with courage and conviction.

Department Vision

To evolve into a centre of academic excellence, developing professionals in the field of electronics and instrumentation to excel in academia and industry.

Department Mission

Facilitate comprehensive knowledge transfer with latest theoretical and practical concepts, developing good relationship with industrial, academic and research institutions thereby moulding competent professionals with social commitment.

Program Educational Objectives (PEOs)

- PEO 1: Graduates will possess engineering skills, sound knowledge and professional attitude, in electronics and instrumentation to become competent engineers.
- PEO 2: Graduates will have confidence to design and develop instrument systems and to take up engineering challenges.
- PEO 3: Graduates will possess commendable leadership qualities, will maintain the attitude to learn new things and will be capable to adapt themselves to industrial scenario.

Program Outcomes (POs)

Engineering Graduates will be able to:

- PO 1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
- PO 2. Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
- PO 3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
- PO 4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
- PO 5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

- PO 6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
- PO 7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and nee for sustainable development.
- PO 8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
- PO 9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
- PO 10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
- PO 11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
- PO 12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Program Specific Outcomes (PSOs)

- PSO 1: Students of the program will have sound technical skills in electronics and instrumentation.
- PSO 2: Students of the program will be capable of developing instrument systems and methods complying with standards.
- PSO 3: Students of the program will be able to learn new concepts, exhibit leadership qualities and adapt to changing industrial scenarios.

Project Outcomes(PROs)

- PRO 1: Studied the working and application of sensors and other electronic components for our project.
- PRO 2: Learned how we could incorporate the knowledge acquired through literature reviews in our project to provide optimal results.
- PRO 3: Got familiarized with Arduino programming and interfacing of sensors.
- PRO 4: Were able to efficiently work as an individual and within a team and productively utilize and manage the available resources including finance.

Acknowledgment

This project report has been possible only due to support and help from various people. This report would not complete unless their contributions are acknowledged.

First of all, We would like to thank Rev. Fr. (Dr.) Jose Kuriedath CMI, Director, Rajagiri School of Engineering & Technology, Kochi and Dr.P S Sreejith, Principal, Rajagiri School of Engineering & Technology, Kochi for giving us an opportunity to do this work.

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Above all, We thank God Almighty for giving us strength, courage and blessings to complete this work.

Abstract

Around 70 million people in this world are mute people. There are children who suffer from Nonverbal Autism. Communication between the people with speech impairment and normal people is very difficult. Normally people with speech impairment use Sign Language to communicate with others. Not each and every person can understand Sign Language. In our project, a prototype is proposed to give speech output for the Sign Language gestures to bridge the communication gap between the people with speech impairment and normal people. This prototype consists of a glove which has flex sensors, gyroscopes and accelerator's embedded on it. These sensors capture the real time gestures made by the user. Arduino Nano micro controller is used to collect data from these sensors and sends it to the PC via Bluetooth. The PC processes the data sent by the Arduino and runs a Machine Learning Algorithm to classify the Sign Language gestures and predicts the word associated with each gesture. Support Vector Machine (SVM) is used for classification. This prototype is very compact and can recognize both American Sign Language (ASL) and Indian Sign Language (ISL). This prototype not only gives speech to the mute people but also makes them multi linguists.

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Chapter 1

Introduction

In this project, a prototype is proposed to give speech output for the Sign Language gestures to bridge the communication gap between the people with speech impairment and normal people. This prototype consists of a glove which has flex sensors, gyroscopes and accelerometers embedded on it. These sensors capture the real time gestures made by the user. Arduino Nano micro controller is used to collect data from these sensors and sends it to the PC. The PC processes the data sent by the Arduino and runs a Machine Learning Algorithm to classify the Sign Language gestures and predicts the word associated with each gesture.

1.1 Problem Definition

Around 70 million people in this world are mute people.People with speech impairment have difficulty in communicating with others. Normally people with speech impairment use Sign Language to communicate with others. Not each and every person can understand Sign Language.

1.2 Objective

We aim to develop a device that can interpret sign language spoken by the deaf-mute community and convert to speech .We also aim to make it available to the user so as to create custom sign language as that would help them not stick to conventional system of sign language's like ASL and ISL

Chapter 2

Literature Review

Some previous works which have been very prominent in the field of HGR, mainly using Flex sensors and Electromyography (EMG) sensors

In their works, Georgi et al.[1] have evaluated a wearable gesture recognition system's performance. The system captures the motions of the arm, hand, and finger.

The fusion of wrist-worn Inertial Measurement Unit (IMU) and forearm's EMG signals was done to infer hand and finger movements. The classifiers used are Hidden

Markov Models. With the above system's help, a recognition rate of 97.8% and 74.3% is observed in session-independent and person-independent recognition, respectively.

Mochammad et al.[2] have processed EMG signals, and they were classified using 16 time-domain feature extraction. Their study was used to classify the thumb, index, middle, ring, and little finger movement. The pattern recognition used Artificial Neural Network (ANN) with two layers of a feed-forward network resulting in a confusion matrix with the above finger movements' accuracy as 100confusion index of 16.7%, an error of 3.3%, and a complete performance of 96.7% was observed.

In their works, Chuck and et al.[3] have used EMG signals and Electropalatogram (EPG) to recognize silent speech. In this case, the electrode signals were recorded from

the larynx and it's sublingual areas, which are further filtered by noise and were trans- formed into features using complex dual quadtree wavelet transforms. The accuracy achieved in the method was 92% in classifying six sub acoustic words.

Xu Zhang et al.[4] have presented a hand gesture framework using a three-axis accelerometer and multichannel EMG. To achieve the final results, a decision tree and multistream hidden Markov models are utilized. While recognizing 72 Chinese Sign Language, the experiment results on 95.3% and 96.3% accuracy for two subjects, i.e., ACC and EMG

Paul d rosero.[5] designed an intelligent electronic glove system able to detect numbers of sign language in order to automate the process of communication between a deaf-mute person and others. This is done by translating the hands move sign language into an oral language. The system contains flex sensors in each finger that is used to collect data that are analyzed through a methodology involving the following stages: (i) Data balancing with the Kennard-Stone (KS), (ii) Comparison of prototypes selection between CHC evolutionary Algorithm and Decremental Reduction Optimization Procedure 3 (DROP3) to define the best one . Subsequently, the K-Nearest Neighbors (kNN) as classifier (iii) is implemented.The proposed methodology met the objective of reducing the greater amount of data in the training set and that when implementing a classifier, it has a high performance. In this way it is possible to store all the alphabet in sign language.

Xianzhi Chu.[6] proposed a sensor-based data acquisition glove for Japanese Sign Language (JSL) hand gesture recognition. To detect the degree of bending of fingers and hand movement information, five flex sensors, an Inertial Measurement Unit (IMU), and three Force Sensing Resistors (FSRs) are employed. An Arduino nano is used to send the data collected to the computer. The average hand gesture identification accuracy for a single subject employing the Support Vector Machine (SVM) and Dynamic Time Wrapping (recognition DTW) algorithms is 96.9% and 94.5 percent, respectively.

Yuichiro Mori.[7] proposed a simple data glove with a gyro sensor that can capture the palm-turning gestures of some Japanese sign language words. In the proposed system, an algorithm determines whether a palm-turning gesture has occurred based on experimentally defined thresholds. Experiments were conducted with eight participants without individual enrolling to evaluate the proposed data glove. the results show that the suggested data glove can collect individual words with an average accuracy of more than 50%. For single subject hand gesture recognition, we used the SVM-based algorithm and the DTW-based algorithm to achieve excellent accuracy. The experimental results demonstrate that the proposed method has a lot of promise for recognising JSL hand gestures. It could be a beneficial tool to help hearing and speech impaired people in their daily life and bridge the communication gap.

Cao Dong[8] proposed using a microsoft kinect to read hand gestures.The paper describes a new method for ASL alphabet recognition using a low-cost depth camera, which is Microsoft's Kinect. A segmented hand configuration is first obtained by using a depth contrast feature based per-pixel classification algorithm. Then, a hierarchical mode-seeking method is developed and implemented to localize hand joint positions under kinematic constraints. Finally, a Random Forest (RF) classifier is built to recognize ASL signs using the joint angles. To validate the performance of this method, a publicly available dataset from Surrey University was used. The results have shown that this method can achieve above 90% accuracy in recognizing 24 static ASL alphabet signs,

Chapter 3

Methodology

In our project we are converting sign language to speech so that people with speech impairment can communicate more freely with others. The proposed system make use of sensors such as mpu 6050 and flex sensors to read the hand gestures and convert it to speech. The project can be divided into 2 parts:

1. Hardware

2. Software

3.1 Hardware

The wearable device consist of a glove mounted with

3.1.1 MPU 6050

The MPU6050 module has a 3-axis Accelerometer and 3-axis Gyroscope. This allows us to measure a system's or object's acceleration, velocity, direction, displacement, and many other motion-related parameters.

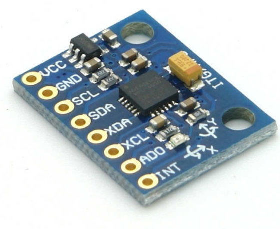


Figure 3.1: MPU 6050

MPU6050 Pinout Configuration		
Pin Number	Pin Name	Description
1	Vcc	Provides power for the module, can be +3V to +5V. Typically +5V is used
2	Ground	Connected to Ground of system
3	Serial Clock(SCL)	Used for providing clock pulse for I2C Communication
4	Serial Data (SDA)	Used for transferring Data through I2C communication
5	Auxiliary Serial Data (XDA)	Can be used to interface other I2C modules with MPU6050. It is optional.
6	Auxiliary Serial Clock (XCL)	Can be used to interface other I2C modules with MPU6050. It is optiona.l
7	AD0	If more than one MPU6050 is used a single MCU, then this pin can be used to vary the address.
8	Interrupt (INT)	Interrupt pin to indicate that data is available for MCU to read

Table 3.1: MPU6050 Pinout Configuration

MPU6050 Features

- MEMS 3-aixs accelerometer and 3-axis gyroscope values combined
- Power Supply: 3-5V
- Communication : I2C protocol
- Built-in 16-bit ADC provides high accuracy
- Built-in DMP provides high computational power
- Can be used to interface with other IIC devices like magnetometer
- Configurable IIC Address
- In-built Temperature sensor

3.1.2 Flex Sensor

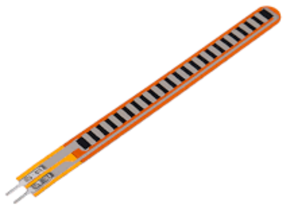


Figure 3.2: Flex Sensor

A flex sensor is a type of sensor that is used to determine the degree of defection or bending. Materials like as plastic and carbon can be used to create this sensor. The carbon surface is set atop a plastic strip that can be turned aside to modify the sensor's resistance. As a result, it's also known as a bend sensor.

Flex sensors come in 2 sizes,4.5 inch and 2.2 inch.In this project we use the 2.2 flex sensor.

This sensor works on the bending strip principle which implies that as the strip is twisted, the resistance changes. This can be determined with the assistance of any controller.

Because the resistance changes when the sensor twists, it works similarly to a variable resistance. The resistance change can depend on the linearity of the surface because the resistance will be dissimilar when it is level.

Specifications & Features

The specifications and features of this sensor include the following.

- Operating voltage of this sensor ranges from 0V to 5V.
- It can function on low-voltages.
- Power rating is 1 Watt for peak & 0.5 Watt for continuous.
- Operating temperature ranges from -45°C to +80°C.
- Flat resistance is 25K Ω.
- The tolerance of resistance will be $+-30$.
- The range of bend resistance will range from 45K-125K Ohms.

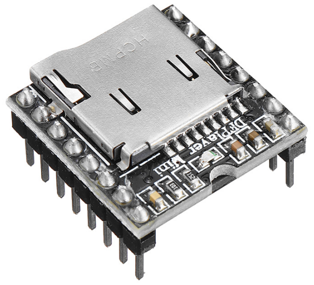


Figure 3.3: DFPlayer Mini

3.1.3 DFPlayer

The DFplayer mini is a small, low-cost mp3 module with a simplified audio output that can be connected directly to a speaker or an earphone jack. The module can be used as a stand-alone module with attached battery, speaker, and push buttons or used in combination with a microcontroller or development board like the Arduino, enabled for RX/TX (Serial) communication, thus through simple serial commands we can play music and perform other functions like playing the next and previous song, shuffle, pause the song currently being played etc. The module comes with an SDcard slot and supports both FAT16, FAT32 file system.

Features

Some of the features of the DF player mini include:

- Support of sampling rate of 8KHz, 11.025KHz, 12KHz, 16KHz, 22.05KHz, up to 48KHz
- 24-bit DAC output, dynamic range support 90dB, SNR supports 85dB
- Supports FAT16, FAT32 file system, maximum support 32GB TF card
- A variety of control modes, serial mode, AD key control mode
- The broadcast language spots feature, you can pause the background music being played
- Built-in 3W amplifier

- The audio data is sorted by folder; supports up to 100 folders, each folder can be assigned to close to 1000 songs
- 30 levels of volume adjustable, 10 levels EQ adjustable.

3.1.4 PAM8403

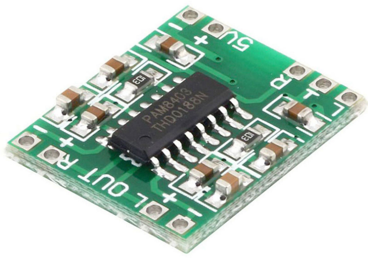


Figure 3.4: PAM8403

PAM8403 is a 3W, class-D audio amplifier. It offers low THD +N, allowing it to achieve high-quality sound reproduction. The new filterless architecture allows the device to drive the speaker directly, requiring no low-pass output filters, thus saving system cost and PCB area. With the same numbers of external components, the efficiency of the PAM8403 is much better than that of Class-AB cousins. It can extend the battery life, which makes it well-suited for portable applications.

Features

- Dual channel stereo output 3 w + 3 w power Class D.
- Works with 2.5V-5V power supply
- High amplification efficiency 85%
- Good sound quality & noise suppression
- Unique without LC filter class D digital power board
- Can use computer USB power supply directly
- Small Size, 1.85 x 2.11 cm can easily fit in a variety of products

3.1.5 Arduino

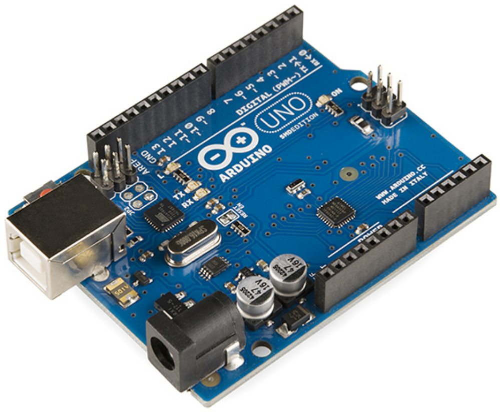


Figure 3.5: Arduino

Arduino UNO is a low-cost, flexible, and easy-to-use programmable open-source microcontroller board that can be integrated into a variety of electronic projects. This board can be interfaced with other Arduino boards, Arduino shields, Raspberry Pi boards and can control relays, LEDs, servos, and motors as an output.

Arduino UNO features AVR microcontroller Atmega328, 6 analogue input pins, and 14 digital I/O pins out of which 6 are used as PWM output which are shown in the fig3.6

This board contains a USB interface i.e. USB cable is used to connect the board with the computer and Arduino IDE (Integrated Development Environment) software is used to program the board.

The unit comes with 32KB flash memory that is used to store the number of instructions while the SRAM is 2KB and EEPROM is 1KB.

The operating voltage of the unit is 5V which projects the microcontroller on the board and its associated circuitry operates at 5V while the input voltage ranges between 6V to 20V and the recommended input voltage ranges from 7V to 12V.

Pin Diagram

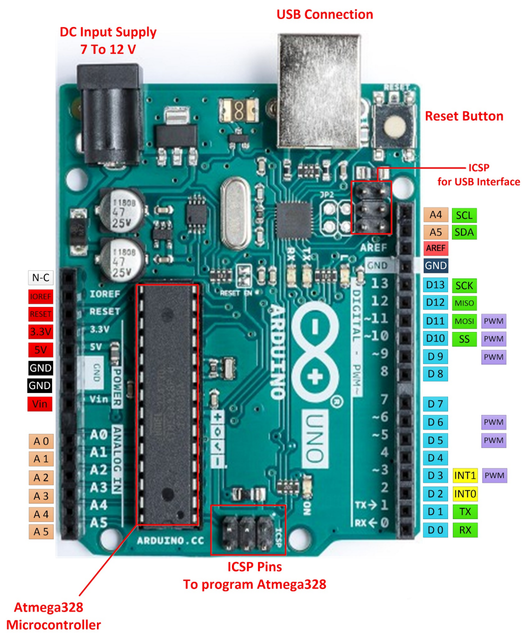


Figure 3.6: Arduino pin diagram

Components of arduino uno

The Arduino UNO board contains the following components and specifications:

- **ATmega328**: This is the brain of the board in which the program is stored.
- **Ground Pin**: There are several ground pins incorporated on the board.
- **PWM**: The board contains 6 PWM pins. PWM stands for Pulse Width Modulation, using this process we can control the speed of the servo motor, DC motor, and brightness of the LED.
- **Digital I/O Pins**: There are 14 digital (0-13) I/O pins available on the board that can be connected with external electronic components.
- **Analogue Pins**: There are 6 analogue pins integrated on the board. These pins can read the analogue sensor and can convert it into a digital signal.
- **AREF**: It is an Analog Reference Pin used to set an external reference voltage.
- **Reset Button**: This button will reset the code loaded into the board. This button is useful when the board hangs up, pressing this button will take the entire board into an initial state.

- **USB Interface**: This interface is used to connect the board with the computer and to upload the Arduino sketches (Arduino Program is called a Sketch)
- **DC Power Jack**: This is used to power up the board with a power supply.
- **Power LED**: This is a power LED that lights up when the board is connected with the power source.
- **Micro SD Card**: The UNO board supports a micro SD card that allows the board to store more information.
- **3.3V**: This pin is used to supply 3.3V power to your projects.
- **5V**: This pin is used to supply 5V power to your projects.
- **VIN**: It is the input voltage applied to the UNO board.
- **Voltage Regulator**: The voltage regulator controls the voltage that goes into the board.
- **SPI**: The SPI stands for Serial Peripheral Interface. Four Pins 10(SS), 11(MOSI), 12(MISO), 13(SCK) are used for this communication.
- **TX/RX**: Pins TX and RX are used for serial communication. The TX is a transmit pin used to transmit the serial data while RX is a receive pin used to receive serial data.

3.1.6 Raspberry pi

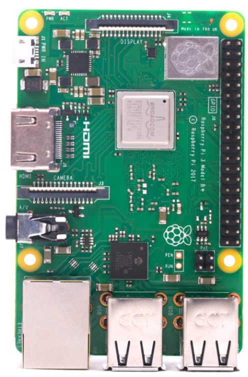


Figure 3.7: Raspberry pi

Raspberry Pi 3 Model B+ has a faster 1.4 GHz processor, a three-times faster gigabit Ethernet (throughput limited to ca. 300 Mbit/s by the internal USB 2.0 connection), and 2.4 / 5 GHz dual-band 802.11ac Wi-Fi (100 Mbit/s). Other features are Power over Ethernet (PoE) (with the add-on PoE HAT), USB boot and network boot (an SD card is no longer required).

Raspberry Pi-3 Pin Configuration

Pin Group	Pin Name	Description
Power Source	+5V, +3.3V, GND and Vin	+ 5V -power output +3.3V -power output GND - GROUND pin
COMMUNICATION INTERFACE	UART Interface(RXD, TXD) [(GPIO15,GPIO14)]	UART (Universal Asynchronous Receiver Transmitter) used for interfacing sensors and other devices.
SPI Interface(MOSI, MISO, CLK,CE) x 2 [SPI0-(GPIO10 ,GPIO9, GPIO11 ,GPIO8)] [SPI1–(GPIO20 ,GPIO19, GPIO21 ,GPIO7)]	SPI (Serial Peripheral Interface) used for communicating with other boards or peripherals.	
TWI Interface(SDA, SCL) x 2 [(GPIO2, GPIO3)] [(ID-SD,ID-SC)]	TWI (Two Wire Interface) Interface can be used to connect peripherals.	
INPUT OUTPUT PINS	26 I/O	Although these some pins have multiple functions they can be considered as I/O pins.
PWM	Hardware PWM available on GPIO12, GPIO13, GPIO18, GPIO19	These 4 channels can provide PWM (Pulse Width Modulation) outputs.
EXTERNAL INTERRUPTS	All I/O	In the board all I/O pins can be used as Interrupts.

Table 3.2: Raspberry Pi 3 Configuration

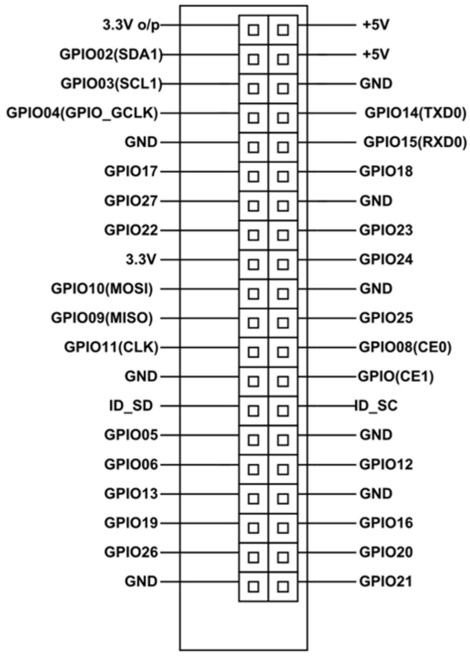


Figure 3.8: Raspberry pi pin

Specifications

- Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
- 1GB RAM
- BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board
- 100 Base Ethernet
- 40-pin extended GPIO
- 4 USB 2 ports
- 4 Pole stereo output and composite video port
- Full size HDMI
- CSI camera port for connecting a Raspberry Pi camera
- DSI display port for connecting a Raspberry Pi touchscreen display
- Micro SD port for loading your operating system and storing data
- Upgraded switched Micro USB power source up to 2.5A

3.2 Software

3.2.1 Arduino IDE

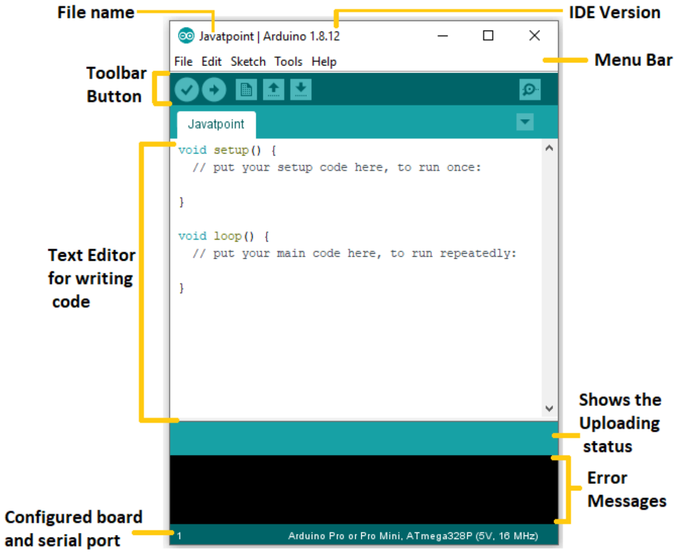


Figure 3.9: Arduino IDE

The Arduino IDE is an open-source software, which is used to write and upload code to the Arduino boards. The IDE application is suitable for different operating systems such as Windows, Mac OS X, and Linux. It supports the programming languages C and C++. Here, IDE stands for Integrated Development Environment. The program or code written in the Arduino IDE is often called as sketching. We need to connect Arduino board with the IDE to upload the sketch written in the Arduino IDE software. The sketch is saved with the extension 'ino'.

3.2.2 Thonny

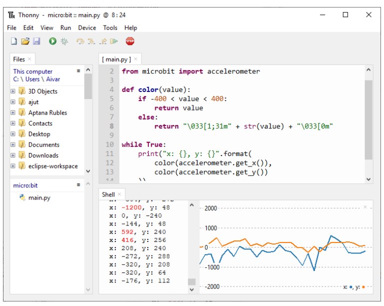


Figure 3.10: Thonny

Thonny is a new Python IDE for learning and teaching programming that can make program visualization a natural part of the beginners' workflow. Among its prominent features are different ways of stepping through the code, step-by-step expression evaluation, intuitive visualization of the call stack and mode for explaining the concepts of references and heap. It supports educational research by logging user actions for replaying or analyzing the programming process. It is free to use and open for extension.

3.2.3 Google Colab

Colaboratory, or "Colab" for short, is a product from Google Research. Colab allows anybody to write and execute arbitrary python code through the browser, and is especially well suited to machine learning, data analysis and education. More technically, Colab is a hosted Jupyter notebook service that requires no setup to use, while providing access free of charge to computing resources including GPUs.

3.3 Construction and Working

The proposed work involves four primary sub-sections i.e., Sensor Interfacing, Data Collection and Pre-processing, Feature Extraction and Selection, and Gesture Recognition.

3.3.1 Sensor Interfacing

Flex sensor (SEN - 08606) is the primary component used in this work. The hardware prototype with flex sensors mounted on fingers is represented in fig 3.11.

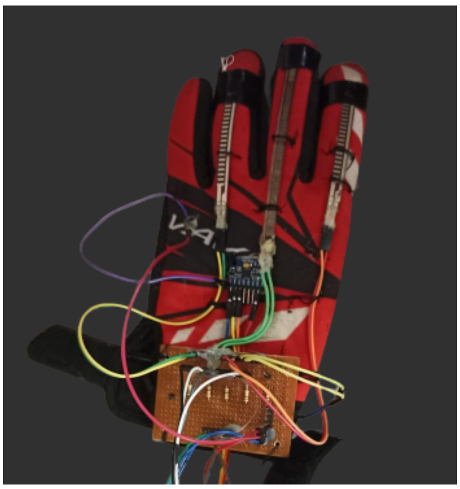


Figure 3.11: Glove

All the used components are illustrated in fig3.12 Flex sensors terminal resistance changes when they are bent, and this helps in detecting the motion in a specific part of the body. The Flex sensor does not contain polarized terminals. So there are no

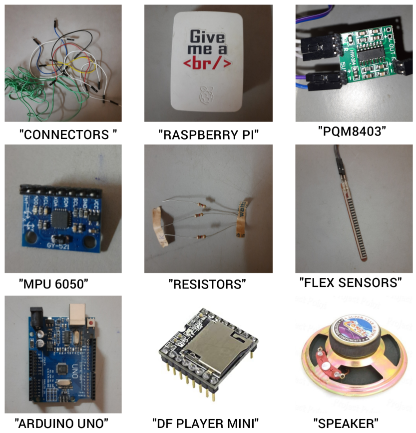


Figure 3.12: Components

positive and negative terminals.

In general, the pin number P1 is connected to positive of power source and P2 is connected to ground, as illustrated in fig3.13. With increase in bent flex in the flex sensor, the resistance increases. The fig3.13 shows the connection followed in order to Interface the Arduino. After properly connecting the sensor with Arduino, the later is connected to PC. With the help of Arduino IDE, a specific designed code is exported

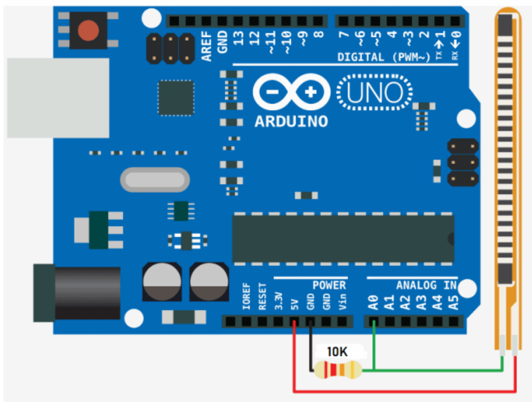


Figure 3.13: Glove Interface

into the Arduino based on which when there is a slight change in the bend of Flex sensor, there is a change observed in the readings obtained as output from the Arduino

3.3.2 Data Collection and Pre-processing

After the above fundamental work, the next level is taking the data from actual conditions of the flex sensors, i.e., when they are attached on fingers and the readings actually measure the bending of each finger they are attached to. The setup was prepared in the following steps:

- In this case, Red riding gloves were worn on the hand. It is done to check the effect of perspiration on the Flex sensors.
- The Flex sensors were then tied on thumb,index finger, middle finger and ring finger of left hand. Insulation tape were used to keep the sensors in place.
- Long copper wires were used to connect the flex sensors to Arduino and resistor as per the circuit diagram.

Data Pre-processing: In this phase, the collected data were categorized on four basic class labels, i.e., Class label 0, Class label 1, Class label 2, Class label 3,Class label 4, Class label 5, Class label 6, Class label 7, Class label 8, Class label 9. The Gestures signified by the Class labels are shown in the fig3.14

Figure 3.14: Signs

The data recorded from each sensor is an integer value. In the interval of 0.2 sec, a new value was obtained based on the change done in bending of the sensor. The two data that is obtained is labelled as x and y in the dataset. The x and y represented the value obtained from the flex sensor tied to index finger and middle finger, respectively

Before the use of the above dataset, shuffling was carefully done by using random library of python. The shuffling ensured sufficient availability of various label data to the machine learning model for training, testing and validation purposes. Some out-layer physical noises were also removed from the dataset.

3.3.3 Gesture Recognition

People who are unable to talk can benefit from the idea of converting hand gestures to speech, which is done in real time by a machine. We tried 3 different approach for classification they are:

1. Random Forest
2. SVM
3. Feed Forward neural network

First we used Random Forest. Bootstrapping is the process of randomly sampling subsets of a dataset over a given number of iterations and a given number of variables. These results are then averaged together to obtain a more powerful result. Bootstrapping is an example of an applied ensemble model.

The bootstrapping Random Forest algorithm combines ensemble learning methods with the decision tree framework to create multiple randomly drawn decision trees from the data, averaging the results to output a new result that often leads to strong predictions/ classifications.

The Random Forest is a powerful tool for classification problems, but as with many machine learning algorithms, it can take a little effort to understand exactly what is being predicted and what it means in context. Luckily, Scikit-Learn makes it easy to run a Random Forest and interpret the results.

Error Metrics for Regression

- Mean Absolute Error
- Mean Squared Error
- Root Mean Squared Error

We then tried SVM classifier for recognising the signs. SVM is a supervised machine learning technique that may be used for both classification and regression. Though we say regression problems as well its best suited for classification. The goal of the SVM algorithm is to find a hyperplane in an N-dimensional space that categorises data points clearly. We have 6 features hence has 6 dimensions

We are using SVM kernel which is a function that takes low dimensional input space and transforms it into higher-dimensional space, ie, it converts not separable problem to separable problem. It is mostly useful in non-linear separation problems. Simply put the kernel, it does some extremely complex data transformations then finds out the process to separate the data based on the labels or outputs defined.

The x and y labels to be fit into the SVM classifier is loaded from the the dataset using the sklearn train test split function, this function shuffle the dataset and randomly select the mentioned amount of data to de trained and tested respectively.in our project we used 70% of the dataset for training and rest 30% for testing the trained model. we trained the model using three differnt kernal for the SVM classifier, they are linear kernel, rbf kernel and poly kernel. Among them we got the best result for linear kernel, thus fixing that for our project.

SVM has many advantages such as effective in high dimensional cases,its memory efficient as it uses a subset of training points in the decision function called support vectors, different kernel functions can be specified for the decision functions and its possible to specify custom kernels

Then we decided to go with neural network because in future we can expand it to different language and models and also the SVM was inefficient on large dataset as well as it requires the picking the right kernal

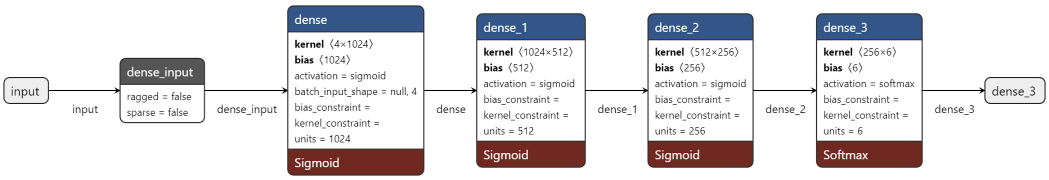


Figure 3.15: Neural network blocks diagram

We made use of Feed forward neural network with 3 hidden layers ,6 different class and 1st layer consist of 1024 in 2nd it has 512 layers and 3rd has 256 and the output layer has 6 nodes as show in the fig3.15 In this model, a series of inputs enter the layer and are multiplied by the weights. Each value is then added together to get a sum of the weighted input values. If the sum of the values is above a specific threshold, usually set at zero, the value produced is often 1, whereas if the sum falls below the threshold, the output value is -1. Using a property known as the delta rule, the neural network can compare the outputs of its nodes with the intended values, thus allowing the network to adjust its weights through training in order to produce more

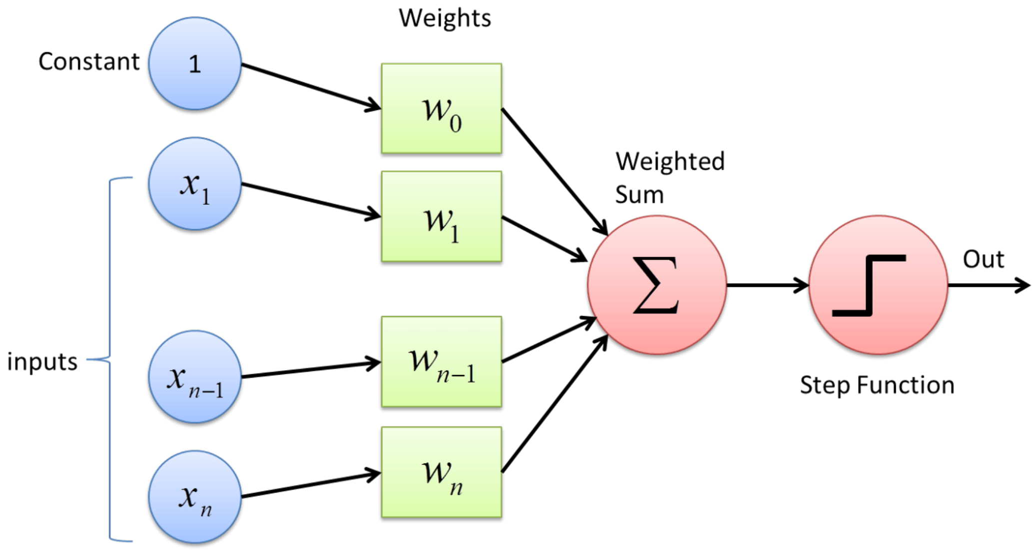


Figure 3.16: Nural network working block

accurate output values the block diagram is shown in fig3.16. This process of training and learning produces a form of a gradient descent. In multi-layered perceptrons, the process of updating weights is nearly analogous, however the process is defined more specifically as back-propagation. In such cases, each hidden layer within the network is adjusted according to the output values produced by the final layer.

Chapter 4

Result

All the proposed modules have been successfully implemented as shown in the fig4.1. We were able to achieve character recognition along with learning algorithm of Random forest, SVM and ANN which can learn more new characters. We hope to extend the project to parse sign languages and other gestures. The glove is fitted with other sensors such as gyros and accelerometers to detect more complex gestures.

Figure 4.1: Glove

We first used **linear regression** for the classification of the signs. In which gets a accuracy of 64.77% as shown in the fig4.2 . Since the accuracy of the linear regression is

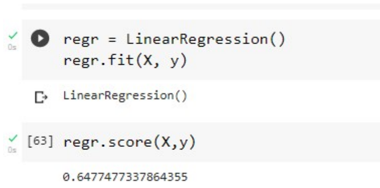


Figure 4.2: Accuracy of linear regression

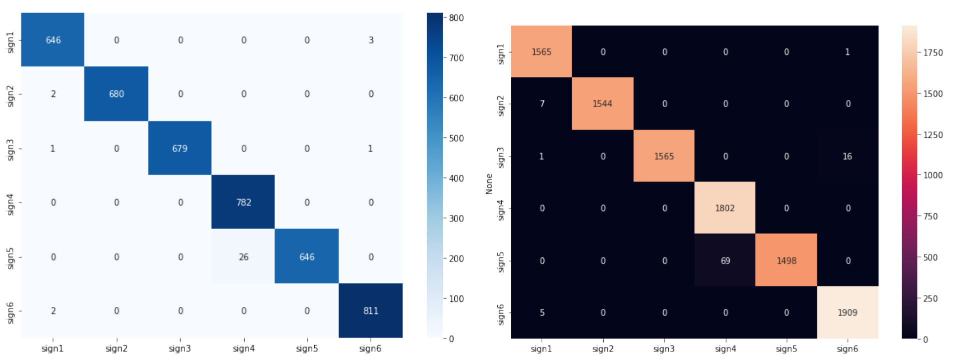
very low, we decided to use **Random forest** which is a a powerful tool for classification problems like the recognition of the gesture. This model is has a accuracy of 99.6%. The error metrics value for regression are shown in table4.1.

Error Metrics	Values
Mean Absolute Error	0.0115167
Mean Squared Error	0.0301362
Root Mean Squared Error	0.173597

Table 4.1: Error Metrics value for Regression

We also used **SVM classifier** to compare the accuracy and SVM classifier got a test accuracy of 99.18205188128068% and training accuracy of 99.0082147% .

We also created a confusion matrix of our model. A confusion matrix is a way to express how many of a classifier's predictions were correct, incorrect and where the classifier got confused in the confusion matrices below fig4.3, the rows represent the true labels and the columns represent predicted labels.



(a) Test Confusion Matrix (b) Train Confusion Matrix

Figure 4.3: Confusion Matrix

Values on the diagonal represent the number (or percent, in a normalized confusion matrix) of times where the predicted label matches the true label. Values in the other cells represent instances where the classifier mislabeled an observation

We created a classification report which is another way to evaluate the classification model performance. It displays the precision, recall, f1 and support scores for the model as shown in the below table4.2 .

F1 score is the weighted harmonic mean of precision and recall. The best possible f1-score would be 1.0 and the worst would be 0.0. F1-score is the harmonic mean of precision and recall. So, f1-score is always lower than accuracy measures as they embed precision and recall into their computation. The weighted average of f1-score should be used to compare classifier models, not global accuracy.

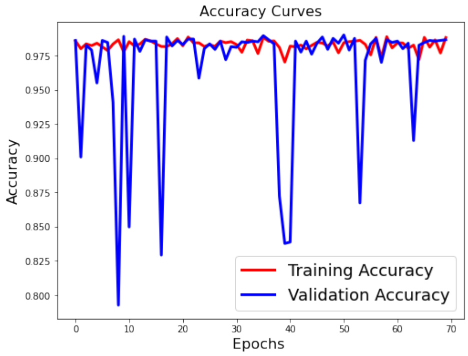
Recall can be defined as the percentage of correctly predicted positive outcomes out of all the actual positive outcomes. It can be given as the ratio of true positives (TP) to the sum of true positives and false negatives (TP + FN). Recall is also called Sensitivity. Recall identifies the proportion of correctly predicted actual positives.

Precision can be defined as the percentage of correctly predicted positive outcomes out of all the predicted positive outcomes. It can be given as the ratio of true positives (TP) to the sum of true and false positives (TP + FP). So, Precision identifies the proportion of correctly predicted positive outcome. It is more concerned with the positive class than the negative class.

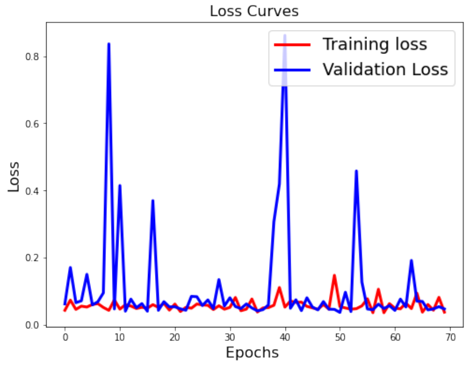
NO:	Precision	recall	f1-score	support
1	0.99	1.00	0.99	649
2	1.00	1.00	1.00	682
3	1.00	1.00	1.00	681
4	0.97	1.00	0.98	782
5	1.00	0.96	0.98	672
6	1.00	1.00	1.00	813

Table 4.2: Classification Report

We created a **Neural network** for the recognition of the gesture and plotted the Accuracy Curves and Loss Curves as shown in bellow the fig4.4



(a) Accuracy Curves



(b) Loss Curves

Figure 4.4: Accuracy Curves and Loss Curves

Comparing the accuracy of 4 different models is shown in bellow table 4.3

Model	Accuracy
Linear Regresssion	0.647747
Random Forest	0.996533
SVM	0.990082
Nural Network	0.990184

Table 4.3: Comparison

Among the models that we used even though RF gives the maximum accuracy for the training of dataset, however we are finalizing the SVM model as using this helps us to expand the project to more number of signs, which are also complex in nature.

Chapter 5

Conclusion and Future Scope

Sign language being the only communication means for mute community, hampers their interaction with the people who lack the knowledge of sign language. Our project has the potential of minimizing this communication barrier by working as an automated translator and convert sign language directly into audio using various flex sensor, accelerometer and Arduino. The input data glove detects the hand gesture done by the person wearing it and provides the analog input to the micro controller for further interpretation according to the database and the final output is the speaker. Thus, hand gesture can be automatically converted with the help of this system such that any one can understand it.

In this project we successfully train the neural network, and SVM model with accuracy above 99% was implemented. In future we can add more signs to this device as there is an accelerometer and gyroscope module attached, this will also help us to add complicated signs. Also to make this more useful, we are planning to add a speech to text converter with display and microphone module. The mic will capture the audio and is converted to text which will be shown on the display. This will help people with hearing impairment to readout from the display.

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Mapping of Project Outcomes

PRO - PO & PRO - PSO Mapping

The following table shows the mapping of different program outcomes and the program specific outcomes to the project outcomes. The mapping specifications are as follows:

- 1-Low
- 2-Medium
- 3-High

Project Outcomes	**PO1**	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
PRO 1	2	-	-	3	-	2	-	-	-	-	-	3	-	-	1
PRO 2	3	2	3	3	-	-	-	-	-	-	-	2	3	-	3
PRO 3	2	2	-	-	3	-	-	-	-	-	-	-	2	2	-
PRO 4	-	-	-	-	-	-	-		3	3	3	-	-	-	2

Table 5.1: PRO-PO & PRO-PSO Mapping

Justification

Project Outcomes (PROs)	POs/ PSOs	Justification
PRO 1	PO 1	Working of MPU6050, Flex sensor and Arduino was studied.
	PO 4	We designed a bridge circuit and calculated the value of resistor necessary for the required sensitivity
	PO 6	Our project was designed in such a way that it is easy to carry around and use.
	PSO 1	Learned the internal working of the sensors and electronic components used in our project.
	PSO 3	Learned the concept of basic machine leaning.
PRO 2	PO 1	We learned how create a basic circuit with Flex sensor and accelerometer.
	PO 2	The variation of the values of flex sensor was found and corrected. Found different libraries for Arduino
	PO 3	We selected the Arduino, DFplayer and MPU6050 because they are user friendly.
	PO 4	We learned about the problems of flex sensor, accelerometer and how to solve it.
PRO 3	PO 1	We learn C programming for creating the Arduino code.
	PO 2	We needed a small controller for interfacing the sensors and collecting data for processing, so we choose Arduino.
	PO 5	Made use of Arduino and machine learning.
	PSO 1	Learned how to collect values from the sensor (MPU6050 and Flex sensor)
	PSO 2	We made the basic circuit for the sensor and speaker and completed the system.
PRO 4	PO 9	We divided our work between our self and each member were assigned a particular task.
	PO 10	During the hardware assembly, all of us came together and interfaced all our parts together into one single system.
	PO 11	We were able to minimize the cost of the project by proper management of components.
	PSO 3	We completed our project with good coordination and team work.

Table 5.2: Justification of the mapping

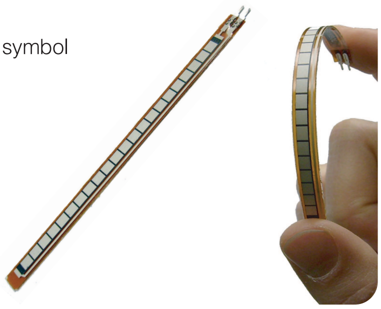
Appendix A

Datasheets

1. Flex Sensor.
2. MPU 6050.
3. Arduino UNO.
4. PAM 8403.
5. DF Player Mini.
6. Rasspberry Pie Model 3 plus

FLEX SENSOR FS

Special Edition Length



Features

- Angle Displacement Measurement
- Bends and Flexes physically with motion device
- Possible Uses
  - Robotics
  - Gaming (Virtual Motion)
  - Medical Devices
  - Computer Peripherals
  - Musical Instruments
  - Physical Therapy
- Simple Construction
- Low Profile

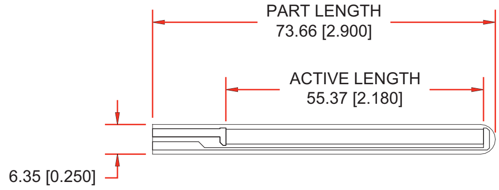
Mechanical Specifications

-Life Cycle: >1 million
-Height: ≤0.43mm (0.017")
-Temperature Range: -35°C to +80°C

Electrical Specifications

-Flat Resistance: 25K Ohms
-Resistance Tolerance: ±30%
-Bend Resistance Range: 45K to 125K Ohms (depending on bend radius)
-Power Rating : 0.50 Watts continuous. 1 Watt Peak

Dimensional Diagram - Stock Flex Sensor



How to Order - Stock Flex Sensor

FS — L — 0055 — 253 — ST

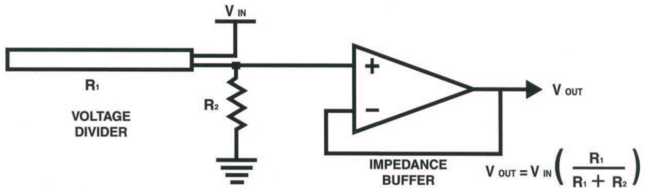
Series	Model	Active Length	Resistance	Connectors
FS = Flex Sensor	L = Linear	0055 = 55.37mm	253 = 25K Ohms	ST = Solder Tab

How It Works

spectrasymbol.com Rev A2 - Page 1 (888) 795-2283

Schematics

BASIC FLEX SENSOR CIRCUIT:

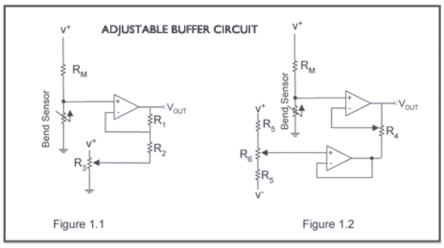


Following are notes from the ITP Flex Sensor Workshop

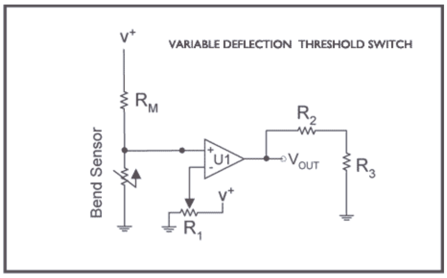
"The impedance buffer in the [Basic Flex Sensor Circuit] (above) is a single sided operational amplifier, used with these sensors because the low bias current of the op amp reduces errer due to source impedance of the flex sensor as voltage divider. Suggested op amps are the LM358 or LM324."

"You can also test your flex sensor using the simplest circut, and skip the op amp."

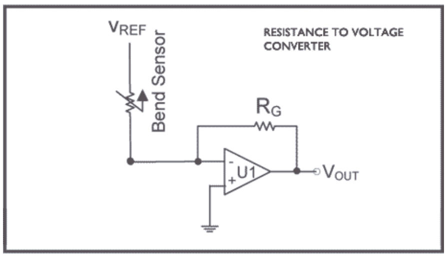
"Adjustable Buffer - a potentiometer can be added to the circuit to adjust the sensitivity range."



"Variable Deflection Threshold Switch - an op amp is used and outputs either high or low depending on the voltage of the inverting input. In this way you can use the flex sensor as a switch without going through a microcontroller."



"Resistance to Voltage Converter - use the sensor as the input of a resistance to voltage converter using a dual sided supply op-amp. A negative reference voltage will give a positive output. Should be used in situations when you want output at a low degree of bending."



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InvenSense	**InvenSense Inc.** 1197 Borregas Ave, Sunnyvale, CA 94089 U.S.A. Tel: +1 (408) 988-7339 Fax: +1 (408) 988-8104 Website: www.invensense.com	Document Number: PS-MPU-6000A-00 Revision: 3.4 Release Date: 08/19/2013

MPU-6000 and MPU-6050 Product Specification Revision 3.4

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InvenSense	MPU-6000/MPU-6050 Product Specification	Document Number: PS-MPU-6000A-00 Revision: 3.4 Release Date: 08/19/2013

1 Revision History

Revision Date	Revision	Description
11/24/2010	1.0	Initial Release
05/19/2011	2.0	For Rev C parts. Clarified wording in sections (3.2, 5.1, 5.2, 6.1-6.4, 6.6, 6.9, 7, 7.1-7.6, 7.11, 7.12, 7.14, 8, 8.2-8.4, 10.3, 10.4, 11, 12.2)
07/28/2011	2.1	Edited supply current numbers for different modes (section 6.4)
08/05/2011	2.2	Unit of measure for accelerometer sensitivity changed from LSB/m*g* to LSB/*g*
10/12/2011	2.3	Updated accelerometer self test specifications in Table 6.2. Updated package dimensions (section 11.2). Updated PCB design guidelines (section 11.3)
10/18/2011	3.0	For Rev D parts. Updated accelerometer specifications in Table 6.2. Updated accelerometer specification note (sections 8.2, 8.3, & 8.4). Updated qualification test plan (section 12.2).
10/24/2011	3.1	Edits for clarity Changed operating voltage range to 2.375V-3.46V Added accelerometer Intelligence Function increment value of 1m*g*/LSB (Section 6.2) Updated absolute maximum rating for acceleration (any axis, unpowered) from 0.3ms to 0.2ms (Section 6.9) Modified absolute maximum rating for Latch-up to Level A and ±100mA (Section 6.9, 12.2)
11/16/2011	3.2	**Updated self-test response specifications for Revision D parts dated with date code 1147 (YYWW) or later.** Edits for clarity Added Gyro self-test (sections 5.1, 6.1, 7.6, 7.12) Added Min/Max limits to Accel self-test response (section 6.2) Updated Accelerometer low power mode operating currents (Section 6.3) Added gyro self test to block diagram (section 7.5) Updated packaging labels and descriptions (sections 11.8 & 11.9)
5/16/2012	3.3	Updated Gyro and Accelerometer self test information (sections 6.1, 6.2, 7.12) Updated latch-up information (Section 6.9) Updated programmable interrupts information (Section 8) Changed shipment information from maximum of 3 reels (15K units) per shipper box to 5 reels (25K units) per shipper box (Section 11.7) Updated packing shipping and label information (Sections 11.8, 11.9) Updated reliability references (Section 12.2)
8/19/2013	3.4	Updates section 4

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2 Purpose and Scope

This product specification provides advanced information regarding the electrical specification and design related information for the MPU-6000™ and MPU-6050™ MotionTracking™ devices, collectively called the MPU-60X0™ or MPU™.

Electrical characteristics are based upon design analysis and simulation results only. Specifications are subject to change without notice. Final specifications will be updated based upon characterization of production silicon. For references to register map and descriptions of individual registers, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

The self-test response specifications provided in this document pertain to Revision D parts with date codes of 1147 (YYWW) or later. Please see Section 11.6 for package marking description details.

3 Product Overview

3.1 MPU-60X0 Overview

MotionInterface™ is becoming a "must-have" function being adopted by smartphone and tablet manufacturers due to the enormous value it adds to the end user experience. In smartphones, it finds use in applications such as gesture commands for applications and phone control, enhanced gaming, augmented reality, panoramic photo capture and viewing, and pedestrian and vehicle navigation. With its ability to precisely and accurately track user motions, MotionTracking technology can convert handsets and tablets into powerful 3D intelligent devices that can be used in applications ranging from health and fitness monitoring to location-based services. Key requirements for MotionInterface enabled devices are small package size, low power consumption, high accuracy and repeatability, high shock tolerance, and application specific performance programmability – all at a low consumer price point.

The MPU-60X0 is the world's first integrated 6-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™ (DMP) all in a small 4x4x0.9mm package. With its dedicated I^2C sensor bus, it directly accepts inputs from an external 3-axis compass to provide a complete 9-axis MotionFusion™ output. The MPU-60X0 MotionTracking device, with its 6-axis integration, on-board MotionFusion™, and run-time calibration firmware, enables manufacturers to eliminate the costly and complex selection, qualification, and system level integration of discrete devices, guaranteeing optimal motion performance for consumers. The MPU-60X0 is also designed to interface with multiple non-inertial digital sensors, such as pressure sensors, on its auxiliary I^2C port. The MPU-60X0 is footprint compatible with the MPU-30X0 family.

The MPU-60X0 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs and three 16-bit ADCs for digitizing the accelerometer outputs. For precision tracking of both fast and slow motions, the parts feature a user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps) and a user-programmable accelerometer full-scale range of ±2*g*, ±4*g*, ±8*g*, and ±16*g*.

An on-chip 1024 Byte FIFO buffer helps lower system power consumption by allowing the system processor to read the sensor data in bursts and then enter a low-power mode as the MPU collects more data. With all the necessary on-chip processing and sensor components required to support many motion-based use cases, the MPU-60X0 uniquely enables low-power MotionInterface applications in portable applications with reduced processing requirements for the system processor. By providing an integrated MotionFusion output, the DMP in the MPU-60X0 offloads the intensive MotionProcessing computation requirements from the system processor, minimizing the need for frequent polling of the motion sensor output.

Communication with all registers of the device is performed using either I^2C at 400kHz or SPI at 1MHz (MPU-6000 only). For applications requiring faster communications, the sensor and interrupt registers may be read using SPI at 20MHz (MPU-6000 only). Additional features include an embedded temperature sensor and an on-chip oscillator with ±1% variation over the operating temperature range.

By leveraging its patented and volume-proven Nasiri-Fabrication platform, which integrates MEMS wafers with companion CMOS electronics through wafer-level bonding, InvenSense has driven the MPU-60X0 package size down to a revolutionary footprint of 4x4x0.9mm (QFN), while providing the highest performance, lowest noise, and the lowest cost semiconductor packaging required for handheld consumer electronic devices. The part features a robust 10,000*g* shock tolerance, and has programmable low-pass filters for the gyroscopes, accelerometers, and the on-chip temperature sensor.

For power supply flexibility, the MPU-60X0 operates from VDD power supply voltage range of 2.375V-3.46V. Additionally, the MPU-6050 provides a VLOGIC reference pin (in addition to its analog supply pin: VDD), which sets the logic levels of its I^2C interface. The VLOGIC voltage may be 1.8V±5% or VDD.

The MPU-6000 and MPU-6050 are identical, except that the MPU-6050 supports the I^2C serial interface only, and has a separate VLOGIC reference pin. The MPU-6000 supports both I^2C and SPI interfaces and has a single supply pin, VDD, which is both the device's logic reference supply and the analog supply for the part. The table below outlines these differences:

InvenSense	**MPU-6000/MPU-6050 Product Specification**	Document Number: PS-MPU-6000A-00 Revision: 3.4 Release Date: 08/19/2013

Primary Differences between MPU-6000 and MPU-6050

Part / Item	MPU-6000	MPU-6050
VDD	2.375V-3.46V	2.375V-3.46V
VLOGIC	n/a	1.71V to VDD
Serial Interfaces Supported	I^2C, SPI	I^2C
Pin 8	/CS	VLOGIC
Pin 9	AD0/SDO	AD0
Pin 23	SCL/SCLK	SCL
Pin 24	SDA/SDI	SDA

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4 Applications

- *BlurFree*™ technology (for Video/Still Image Stabilization)
- *AirSign*™ technology (for Security/Authentication)
- *TouchAnywhere*™ technology (for “no touch” UI Application Control/Navigation)
- *MotionCommand*™ technology (for Gesture Short-cuts)
- Motion-enabled game and application framework
- InstantGesture™ iG™ gesture recognition
- Location based services, points of interest, and dead reckoning
- Handset and portable gaming
- Motion-based game controllers
- 3D remote controls for Internet connected DTVs and set top boxes, 3D mice
- Wearable sensors for health, fitness and sports
- Toys

5 Features

5.1 Gyroscope Features

The triple-axis MEMS gyroscope in the MPU-60X0 includes a wide range of features:

- Digital-output X-, Y-, and Z-Axis angular rate sensors (gyroscopes) with a user-programmable full-scale range of ±250, ±500, ±1000, and ±2000°/sec
- External sync signal connected to the FSYNC pin supports image, video and GPS synchronization
- Integrated 16-bit ADCs enable simultaneous sampling of gyros
- Enhanced bias and sensitivity temperature stability reduces the need for user calibration
- Improved low-frequency noise performance
- Digitally-programmable low-pass filter
- Gyroscope operating current: 3.6mA
- Standby current: 5µA
- Factory calibrated sensitivity scale factor
- User self-test

5.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-60X0 includes a wide range of features:

- Digital-output triple-axis accelerometer with a programmable full scale range of ±2*g*, ±4*g*, ±8*g* and ±16*g*
- Integrated 16-bit ADCs enable simultaneous sampling of accelerometers while requiring no external multiplexer
- Accelerometer normal operating current: 500µA
- Low power accelerometer mode current: 10µA at 1.25Hz, 20µA at 5Hz, 60µA at 20Hz, 110µA at 40Hz
- Orientation detection and signaling
- Tap detection
- User-programmable interrupts
- High-G interrupt
- User self-test

5.3 Additional Features

The MPU-60X0 includes the following additional features:

- 9-Axis MotionFusion by the on-chip Digital Motion Processor (DMP)
- Auxiliary master I^2C bus for reading data from external sensors (e.g., magnetometer)
- 3.9mA operating current when all 6 motion sensing axes and the DMP are enabled
- VDD supply voltage range of 2.375V-3.46V
- Flexible VLOGIC reference voltage supports multiple I^2C interface voltages (MPU-6050 only)
- Smallest and thinnest QFN package for portable devices: 4x4x0.9mm
- Minimal cross-axis sensitivity between the accelerometer and gyroscope axes
- 1024 byte FIFO buffer reduces power consumption by allowing host processor to read the data in bursts and then go into a low-power mode as the MPU collects more data
- Digital-output temperature sensor
- User-programmable digital filters for gyroscope, accelerometer, and temp sensor
- 10,000 *g* shock tolerant
- 400kHz Fast Mode I^2C for communicating with all registers
- 1MHz SPI serial interface for communicating with all registers (MPU-6000 only)
- 20MHz SPI serial interface for reading sensor and interrupt registers (MPU-6000 only)

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- MEMS structure hermetically sealed and bonded at wafer level
- RoHS and Green compliant

5.4 MotionProcessing

- Internal Digital Motion Processing™ (DMP™) engine supports 3D MotionProcessing and gesture recognition algorithms
- The MPU-60X0 collects gyroscope and accelerometer data while synchronizing data sampling at a user defined rate. The total dataset obtained by the MPU-60X0 includes 3-Axis gyroscope data, 3-Axis accelerometer data, and temperature data. The MPU's calculated output to the system processor can also include heading data from a digital 3-axis third party magnetometer.
- The FIFO buffers the complete data set, reducing timing requirements on the system processor by allowing the processor burst read the FIFO data. After burst reading the FIFO data, the system processor can save power by entering a low-power sleep mode while the MPU collects more data.
- Programmable interrupt supports features such as gesture recognition, panning, zooming, scrolling, tap detection, and shake detection
- Digitally-programmable low-pass filters
- Low-power pedometer functionality allows the host processor to sleep while the DMP maintains the step count.

5.5 Clocking

- On-chip timing generator ±1% frequency variation over full temperature range
- Optional external clock inputs of 32.768kHz or 19.2MHz

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6 Electrical Characteristics

6.1 Gyroscope Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
GYROSCOPE SENSITIVITY						
Full-Scale Range	FS_SEL=0		±250		º/s	
	FS_SEL=1		±500		º/s	
	FS_SEL=2		±1000		º/s	
	FS_SEL=3		±2000		º/s	
Gyroscope ADC Word Length			16		bits	
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(º/s)	
	FS_SEL=1		65.5		LSB/(º/s)	
	FS_SEL=2		32.8		LSB/(º/s)	
	FS_SEL=3		16.4		LSB/(º/s)	
Sensitivity Scale Factor Tolerance	25°C	-3		+3	%	
Sensitivity Scale Factor Variation Over Temperature			±2		%	
Nonlinearity	Best fit straight line; 25°C		0.2		%	
Cross-Axis Sensitivity			±2		%	
GYROSCOPE ZERO-RATE OUTPUT (ZRO)						
Initial ZRO Tolerance	25°C		±20		º/s	
ZRO Variation Over Temperature	-40°C to +85°C		±20		º/s	
Power-Supply Sensitivity (1-10Hz)	Sine wave, 100mVpp; VDD=2.5V		0.2		º/s	
Power-Supply Sensitivity (10 - 250Hz)	Sine wave, 100mVpp; VDD=2.5V		0.2		º/s	
Power-Supply Sensitivity (250Hz - 100kHz)	Sine wave, 100mVpp; VDD=2.5V		4		º/s	
Linear Acceleration Sensitivity	Static		0.1		º/s/*g*	
SELF-TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	1
GYROSCOPE NOISE PERFORMANCE	**FS_SEL=0**					
Total RMS Noise	DLPFCFG=2 (100Hz)		0.05		º/s-rms	
Low-frequency RMS noise	Bandwidth 1Hz to10Hz		0.033		º/s-rms	
Rate Noise Spectral Density	At 10Hz		0.005		º/s/ √Hz	
GYROSCOPE MECHANICAL FREQUENCIES						
X-Axis		30	33	36	kHz	
Y-Axis		27	30	33	kHz	
Z-Axis		24	27	30	kHz	
LOW PASS FILTER RESPONSE						
	Programmable Range	5		256	Hz	
OUTPUT DATA RATE						
	Programmable	4		8,000	Hz	
GYROSCOPE START-UP TIME	**DLPFCFG=0**					
ZRO Settling (from power-on)	to ±1º/s of Final		30		ms	

1. Please refer to the following document for further information on Self-Test: *MPU-6000/MPU-6050 Register Map and Descriptions*

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6.2 Accelerometer Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
ACCELEROMETER SENSITIVITY						
Full-Scale Range	AFS_SEL=0		±2		*g*	
	AFS_SEL=1		±4		*g*	
	AFS_SEL=2		±8		*g*	
	AFS_SEL=3		±16		*g*	
ADC Word Length	Output in two's complement format		16		bits	
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*	
	AFS_SEL=1		8,192		LSB/*g*	
	AFS_SEL=2		4,096		LSB/*g*	
	AFS_SEL=3		2,048		LSB/*g*	
Initial Calibration Tolerance			±3		%	
Sensitivity Change vs. Temperature	AFS_SEL=0, -40°C to +85°C		±0.02		%/°C	
Nonlinearity	Best Fit Straight Line		0.5		%	
Cross-Axis Sensitivity			±2		%	
ZERO-G OUTPUT						
Initial Calibration Tolerance	X and Y axes		±50		m*g*	1
	Z axis		±80		m*g*	
Zero-G Level Change vs. Temperature	X and Y axes, 0°C to +70°C		±35			
	Z axis, 0°C to +70°C		±60		m*g*	
SELF TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	2
NOISE PERFORMANCE						
Power Spectral Density	@10Hz, AFS_SEL=0 & ODR=1kHz		400		μ*g*/ √Hz	
LOW PASS FILTER RESPONSE						
	Programmable Range	5		260	Hz	
OUTPUT DATA RATE						
	Programmable Range	4		1,000	Hz	
INTELLIGENCE FUNCTION INCREMENT			32		mg/LSB	

1. Typical zero-g initial calibration tolerance value after MSL3 preconditioning
2. Please refer to the following document for further information on Self-Test: *MPU-6000/MPU-6050 Register Map and Descriptions*

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6.3 Electrical and Other Common Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
TEMPERATURE SENSOR						
Range			-40 to +85		°C	
Sensitivity	Untrimmed		340		LSB/ºC	
Temperature Offset	35°C		-521		LSB	
Linearity	Best fit straight line (-40°C to +85°C)		±1		°C	
VDD POWER SUPPLY						
Operating Voltages		2.375		3.46	V	
Normal Operating Current	Gyroscope + Accelerometer + DMP		3.9		mA	
	Gyroscope + Accelerometer (DMP disabled)		3.8		mA	
	Gyroscope + DMP (Accelerometer disabled)		3.7		mA	
	Gyroscope only (DMP & Accelerometer disabled)		3.6		mA	
	Accelerometer only (DMP & Gyroscope disabled)		500		µA	
Accelerometer Low Power Mode Current	1.25 Hz update rate		10		µA	
	5 Hz update rate		20		µA	
	20 Hz update rate		70		µA	
	40 Hz update rate		140		µA	
Full-Chip Idle Mode Supply Current			5		µA	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			100	ms	
VLOGIC REFERENCE VOLTAGE	MPU-6050 only					
Voltage Range	VLOGIC must be ≤VDD at all times	1.71		VDD	V	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			3	ms	
Normal Operating Current			100		µA	
TEMPERATURE RANGE						
Specified Temperature Range	Performance parameters are not applicable beyond Specified Temperature Range	-40		+85	°C	

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6.4 Electrical Specifications, Continued

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SERIAL INTERFACE						
SPI Operating Frequency, All Registers Read/Write	MPU-6000 only, Low Speed Characterization		100 ±10%		kHz	
	MPU-6000 only, High Speed Characterization		1 ±10%		MHz	
SPI Operating Frequency, Sensor and Interrupt Registers Read Only	MPU-6000 only		20 ±10%		MHz	
I^2C Operating Frequency	All registers, Fast-mode			400	kHz	
	All registers, Standard-mode			100	kHz	
I^2C ADDRESS	AD0 = 0		1101000			
	AD0 = 1		1101001			
DIGITAL INPUTS (SDI/SDA, AD0, SCLK/SCL, FSYNC, /CS, CLKIN)						
V_{IH}, High Level Input Voltage	MPU-6000	0.7*VDD			V	
	MPU-6050	0.7*VLOGIC			V	
V_{IL}, Low Level Input Voltage	MPU-6000			0.3*VDD	V	
	MPU-6050			0.3*VLOGIC	V	
C_I, Input Capacitance			< 5		pF	
DIGITAL OUTPUT (SDO, INT)						
V_{OH}, High Level Output Voltage	R_{LOAD}=1MΩ; MPU-6000	0.9*VDD			V	
	R_{LOAD}=1MΩ; MPU-6050	0.9*VLOGIC			V	
V_{OL1}, LOW-Level Output Voltage	R_{LOAD}=1MΩ; MPU-6000			0.1*VDD	V	
	R_{LOAD}=1MΩ; MPU-6050			0.1*VLOGIC	V	
$V_{OL.INT1}$, INT Low-Level Output Voltage	OPEN=1, 0.3mA sink Current			0.1	V	
Output Leakage Current	OPEN=1		100		nA	
t_{INT}, INT Pulse Width	LATCH_INT_EN=0		50		µs	

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6.5 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Typical	Units	Notes
Primary I²C I/O (SCL, SDA)				
V_{IL}, LOW-Level Input Voltage	MPU-6000	-0.5 to 0.3*VDD	V	
V_{IH}, HIGH-Level Input Voltage	MPU-6000	0.7*VDD to VDD + 0.5V	V	
V_{hys}, Hysteresis	MPU-6000	0.1*VDD	V	
VIL, LOW Level Input Voltage	MPU-6050	-0.5V to 0.3*VLOGIC	V	
VIH, HIGH-Level Input Voltage	MPU-6050	0.7*VLOGIC to VLOGIC + 0.5V	V	
Vhys, Hysteresis	MPU-6050	0.1*VLOGIC	V	
V_{OL1}, LOW-Level Output Voltage	3mA sink current	0 to 0.4	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V	3	mA	
	V_{OL} = 0.6V	5	mA	
Output Leakage Current		100	nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pF	20+0.1C_b to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	
Auxiliary I²C I/O (AUX_CL, AUX_DA)	**MPU-6050: *AUX_VDDIO*=0**			
V_{IL}, LOW-Level Input Voltage		-0.5V to 0.3*VLOGIC	V	
V_{IH}, HIGH-Level Input Voltage		0.7*VLOGIC to VLOGIC + 0.5V	V	
V_{hys}, Hysteresis		0.1*VLOGIC	V	
V_{OL1}, LOW-Level Output Voltage	VLOGIC > 2V; 1mA sink current	0 to 0.4	V	
V_{OL3}, LOW-Level Output Voltage	VLOGIC < 2V; 1mA sink current	0 to 0.2*VLOGIC	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V V_{OL} = 0.6V	1 1	mA mA	
Output Leakage Current		100	nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pF	20+0.1C_b to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	

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6.6 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Min	Typical	Max	Units	Notes
INTERNAL CLOCK SOURCE	**CLK_SEL=0,1,2,3**					
Gyroscope Sample Rate, Fast	DLPFCFG=0 SAMPLERATEDIV = 0		8		kHz	
Gyroscope Sample Rate, Slow	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1		kHz	
Accelerometer Sample Rate			1		kHz	
Clock Frequency Initial Tolerance	CLK_SEL=0, 25°C	-5		+5	%	
	CLK_SEL=1,2,3; 25°C	-1		+1	%	
Frequency Variation over Temperature	CLK_SEL=0		-15 to +10		%	
	CLK_SEL=1,2,3		±1		%	
PLL Settling Time	CLK_SEL=1,2,3		1	10	ms	
EXTERNAL 32.768kHz CLOCK	**CLK_SEL=4**					
External Clock Frequency			32.768		kHz	
External Clock Allowable Jitter	Cycle-to-cycle rms		1 to 2		µs	
Gyroscope Sample Rate, Fast	DLPFCFG=0 SAMPLERATEDIV = 0		8.192		kHz	
Gyroscope Sample Rate, Slow	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1.024		kHz	
Accelerometer Sample Rate			1.024		kHz	
PLL Settling Time			1	10	ms	
EXTERNAL 19.2MHz CLOCK	**CLK_SEL=5**					
External Clock Frequency			19.2		MHz	
Gyroscope Sample Rate	Full programmable range	3.9		8000	Hz	
Gyroscope Sample Rate, Fast Mode	DLPFCFG=0 SAMPLERATEDIV = 0		8		kHz	
Gyroscope Sample Rate, Slow Mode	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1		kHz	
Accelerometer Sample Rate			1		kHz	
PLL Settling Time			1	10	ms	

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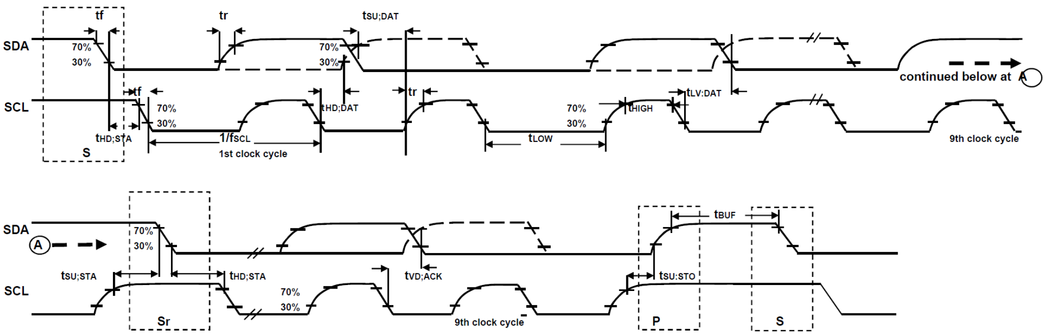
6.7 I^2C Timing Characterization

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

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

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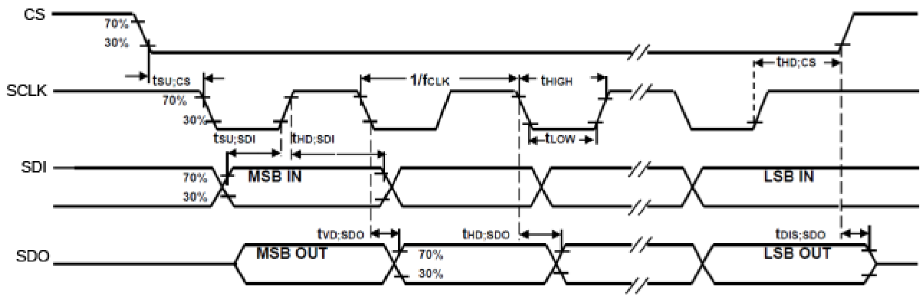
6.8 SPI Timing Characterization (MPU-6000 only)

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD,T_A = 25°C, unless otherwise noted.

Parameters	Conditions	Min	Typical	Max	Units	Notes
SPI TIMING						
f_{SCLK}, SCLK Clock Frequency				1	MHz	
t_{LOW}, SCLK Low Period		400			ns	
t_{HIGH}, SCLK High Period		400			ns	
$t_{SU.CS}$, CS Setup Time		8			ns	
$t_{HD.CS}$, CS Hold Time		500			ns	
$t_{SU.SDI}$, SDI Setup Time		11			ns	
$t_{HD.SDI}$, SDI Hold Time		7			ns	
$t_{VD.SDO}$, SDO Valid Time	C_{load} = 20pF			100	ns	
$t_{HD.SDO}$, SDO Hold Time	C_{load} = 20pF	4			ns	
$t_{DIS.SDO}$, SDO Output Disable Time				10	ns	



SPI Bus Timing Diagram

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6.9 Absolute Maximum Ratings

Stress above those listed as "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these conditions is not implied. Exposure to the absolute maximum ratings conditions for extended periods may affect device reliability.

Parameter	Rating
Supply Voltage, VDD	-0.5V to +6V
VLOGIC Input Voltage Level (MPU-6050)	-0.5V to VDD + 0.5V
REGOUT	-0.5V to 2V
Input Voltage Level (CLKIN, AUX_DA, AD0, FSYNC, INT, SCL, SDA)	-0.5V to VDD + 0.5V
CPOUT (2.5V ≤ VDD ≤ 3.6V)	-0.5V to 30V
Acceleration (Any Axis, unpowered)	10,000g for 0.2ms
Operating Temperature Range	-40°C to +105°C
Storage Temperature Range	-40°C to +125°C
Electrostatic Discharge (ESD) Protection	2kV (HBM); 250V (MM)
Latch-up	JEDEC Class II (2),125°C ±100mA

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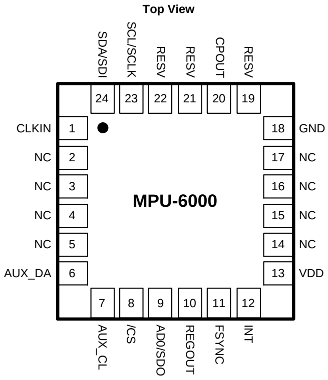
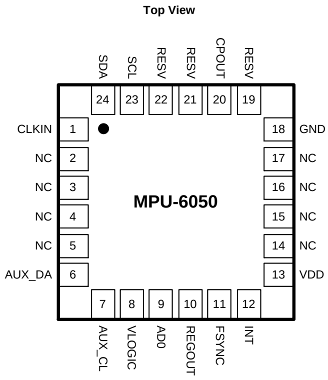
7 Applications Information

7.1 Pin Out and Signal Description

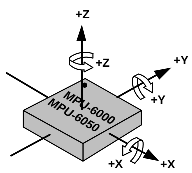
Pin Number	MPU-6000	MPU-6050	Pin Name	Pin Description
1	Y	Y	CLKIN	Optional external reference clock input. Connect to GND if unused.
6	Y	Y	AUX_DA	I^2C master serial data, for connecting to external sensors
7	Y	Y	AUX_CL	I^2C Master serial clock, for connecting to external sensors
8	Y		/CS	SPI chip select (0=SPI mode)
8		Y	VLOGIC	Digital I/O supply voltage
9	Y		AD0 / SDO	I^2C Slave Address LSB (AD0); SPI serial data output (SDO)
9		Y	AD0	I^2C Slave Address LSB (AD0)
10	Y	Y	REGOUT	Regulator filter capacitor connection
11	Y	Y	FSYNC	Frame synchronization digital input. Connect to GND if unused.
12	Y	Y	INT	Interrupt digital output (totem pole or open-drain)
13	Y	Y	VDD	Power supply voltage and Digital I/O supply voltage
18	Y	Y	GND	Power supply ground
19, 21	Y	Y	RESV	Reserved. Do not connect.
20	Y	Y	CPOUT	Charge pump capacitor connection
22	Y	Y	RESV	Reserved. Do not connect.
23	Y		SCL / SCLK	I^2C serial clock (SCL); SPI serial clock (SCLK)
23		Y	SCL	I^2C serial clock (SCL)
24	Y		SDA / SDI	I^2C serial data (SDA); SPI serial data input (SDI)
24		Y	SDA	I^2C serial data (SDA)
2, 3, 4, 5, 14, 15, 16, 17	Y	Y	NC	Not internally connected. May be used for PCB trace routing.



QFN Package
24-pin, 4mm x 4mm x 0.9mm



QFN Package
24-pin, 4mm x 4mm x 0.9mm



Orientation of Axes of Sensitivity and Polarity of Rotation

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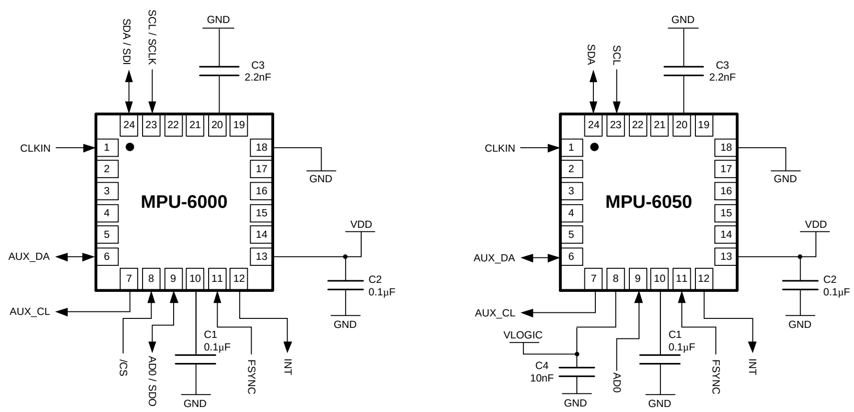
7.2 Typical Operating Circuit



Typical Operating Circuits

7.3 Bill of Materials for External Components

Component	Label	Specification	Quantity
Regulator Filter Capacitor (Pin 10)	C1	Ceramic, X7R, 0.1µF ±10%, 2V	1
VDD Bypass Capacitor (Pin 13)	C2	Ceramic, X7R, 0.1µF ±10%, 4V	1
Charge Pump Capacitor (Pin 20)	C3	Ceramic, X7R, 2.2nF ±10%, 50V	1
VLOGIC Bypass Capacitor (Pin 8)	C4*	Ceramic, X7R, 10nF ±10%, 4V	1

* MPU-6050 Only.

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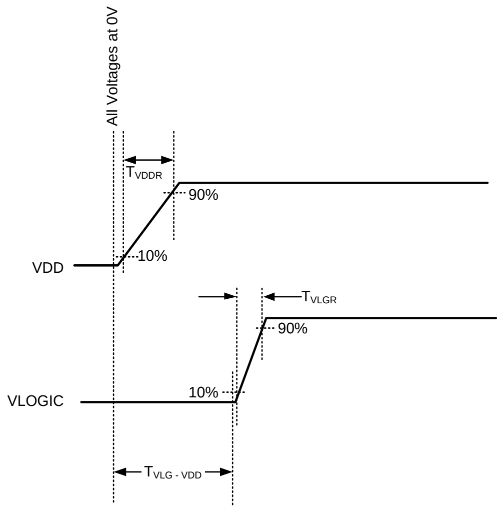
7.4 Recommended Power-on Procedure



Power-Up Sequencing

1. VLOGIC amplitude must always be ≤VDD amplitude
2. T_{VDDR} is VDD rise time: Time for VDD to rise from 10% to 90% of its final value
3. T_{VDDR} is ≤100ms
4. T_{VLGR} is VLOGIC rise time: Time for VLOGIC to rise from 10% to 90% of its final value
5. T_{VLGR} is ≤3ms
6. $T_{VLG-VDD}$ is the delay from the start of VDD ramp to the start of VLOGIC rise
7. $T_{VLG-VDD}$ is ≥0
8. VDD and VLOGIC must be monotonic ramps

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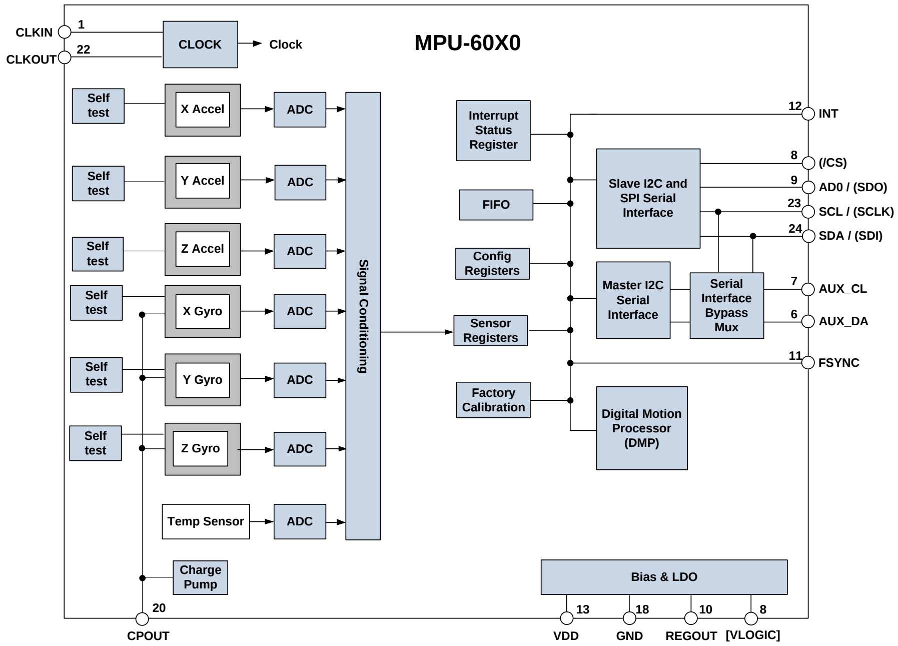
7.5 Block Diagram



Note: Pin names in round brackets ( ) apply only to MPU-6000
Pin names in square brackets [ ] apply only to MPU-6050

7.6 Overview

The MPU-60X0 is comprised of the following key blocks and functions:

- Three-axis MEMS rate gyroscope sensor with 16-bit ADCs and signal conditioning
- Three-axis MEMS accelerometer sensor with 16-bit ADCs and signal conditioning
- Digital Motion Processor (DMP) engine
- Primary I^{2}C and SPI (MPU-6000 only) serial communications interfaces
- Auxiliary I^{2}C serial interface for 3rd party magnetometer & other sensors
- Clocking
- Sensor Data Registers
- FIFO
- Interrupts
- Digital-Output Temperature Sensor
- Gyroscope & Accelerometer Self-test
- Bias and LDO
- Charge Pump

7.7 Three-Axis MEMS Gyroscope with 16-bit ADCs and Signal Conditioning

The MPU-60X0 consists of three independent vibratory MEMS rate gyroscopes, which detect rotation about the X-, Y-, and Z- Axes. When the gyros are rotated about any of the sense axes, the Coriolis Effect causes a vibration that is detected by a capacitive pickoff. The resulting signal is amplified, demodulated, and filtered to produce a voltage that is proportional to the angular rate. This voltage is digitized using individual on-chip 16-bit Analog-to-Digital Converters (ADCs) to sample each axis. The full-scale range of the gyro sensors may be digitally programmed to ±250, ±500, ±1000, or ±2000 degrees per second (dps). The ADC sample rate is programmable from 8,000 samples per second, down to 3.9 samples per second, and user-selectable low-pass filters enable a wide range of cut-off frequencies.

7.8 Three-Axis MEMS Accelerometer with 16-bit ADCs and Signal Conditioning

The MPU-60X0's 3-Axis accelerometer uses separate proof masses for each axis. Acceleration along a particular axis induces displacement on the corresponding proof mass, and capacitive sensors detect the displacement differentially. The MPU-60X0's architecture reduces the accelerometers' susceptibility to fabrication variations as well as to thermal drift. When the device is placed on a flat surface, it will measure 0*g* on the X- and Y-axes and +1*g* on the Z-axis. The accelerometers' scale factor is calibrated at the factory and is nominally independent of supply voltage. Each sensor has a dedicated sigma-delta ADC for providing digital outputs. The full scale range of the digital output can be adjusted to ±2*g*, ±4*g*, ±8*g*, or ±16*g*.

7.9 Digital Motion Processor

The embedded Digital Motion Processor (DMP) is located within the MPU-60X0 and offloads computation of motion processing algorithms from the host processor. The DMP acquires data from accelerometers, gyroscopes, and additional 3rd party sensors such as magnetometers, and processes the data. The resulting data can be read from the DMP's registers, or can be buffered in a FIFO. The DMP has access to one of the MPU's external pins, which can be used for generating interrupts.

The purpose of the DMP is to offload both timing requirements and processing power from the host processor. Typically, motion processing algorithms should be run at a high rate, often around 200Hz, in order to provide accurate results with low latency. This is required even if the application updates at a much lower rate; for example, a low power user interface may update as slowly as 5Hz, but the motion processing should still run at 200Hz. The DMP can be used as a tool in order to minimize power, simplify timing, simplify the software architecture, and save valuable MIPS on the host processor for use in the application.

7.10 Primary I^{2}C and SPI Serial Communications Interfaces

The MPU-60X0 communicates to a system processor using either a SPI (MPU-6000 only) or an I^{2}C serial interface. The MPU-60X0 always acts as a slave when communicating to the system processor. The LSB of the of the I^{2}C slave address is set by pin 9 (AD0).

The logic levels for communications between the MPU-60X0 and its master are as follows:

- MPU-6000: The logic level for communications with the master is set by the voltage on VDD
- MPU-6050: The logic level for communications with the master is set by the voltage on VLOGIC

For further information regarding the logic levels of the MPU-6050, please refer to Section 10.

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7.11 Auxiliary I^2C Serial Interface

The MPU-60X0 has an auxiliary I^2C bus for communicating to an off-chip 3-Axis digital output magnetometer or other sensors. This bus has two operating modes:

- I^2C Master Mode: The MPU-60X0 acts as a master to any external sensors connected to the auxiliary I^2C bus
- Pass-Through Mode: The MPU-60X0 directly connects the primary and auxiliary I^2C buses together, allowing the system processor to directly communicate with any external sensors.

Auxiliary I^2C Bus Modes of Operation:

- I^2C Master Mode: Allows the MPU-60X0 to directly access the data registers of external digital sensors, such as a magnetometer. In this mode, the MPU-60X0 directly obtains data from auxiliary sensors, allowing the on-chip DMP to generate sensor fusion data without intervention from the system applications processor.

  For example, In I^2C Master mode, the MPU-60X0 can be configured to perform burst reads, returning the following data from a magnetometer:

  - X magnetometer data (2 bytes)
  - Y magnetometer data (2 bytes)
  - Z magnetometer data (2 bytes)

  The I^2C Master can be configured to read up to 24 bytes from up to 4 auxiliary sensors. A fifth sensor can be configured to work single byte read/write mode.

- Pass-Through Mode: Allows an external system processor to act as master and directly communicate to the external sensors connected to the auxiliary I^2C bus pins (AUX_DA and AUX_CL). In this mode, the auxiliary I^2C bus control logic (3rd party sensor interface block) of the MPU-60X0 is disabled, and the auxiliary I^2C pins AUX_DA and AUX_CL (Pins 6 and 7) are connected to the main I^2C bus (Pins 23 and 24) through analog switches.

  Pass-Through Mode is useful for configuring the external sensors, or for keeping the MPU-60X0 in a low-power mode when only the external sensors are used.

  In Pass-Through Mode the system processor can still access MPU-60X0 data through the I^2C interface.

Auxiliary I^2C Bus IO Logic Levels

- MPU-6000: The logic level of the auxiliary I^2C bus is VDD
- MPU-6050: The logic level of the auxiliary I^2C bus can be programmed to be either VDD or VLOGIC

For further information regarding the MPU-6050's logic levels, please refer to Section 10.2.

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7.12 Self-Test

Please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document for more details on self test.

Self-test allows for the testing of the mechanical and electrical portions of the sensors. The self-test for each measurement axis can be activated by means of the gyroscope and accelerometer self-test registers (registers 13 to 16).

When self-test is activated, the electronics cause the sensors to be actuated and produce an output signal. The output signal is used to observe the self-test response.

The self-test response is defined as follows:

Self-test response = Sensor output with self-test enabled – Sensor output without self-test enabled

The self-test response for each accelerometer axis is defined in the accelerometer specification table (Section 6.2), while that for each gyroscope axis is defined in the gyroscope specification table (Section 6.1).

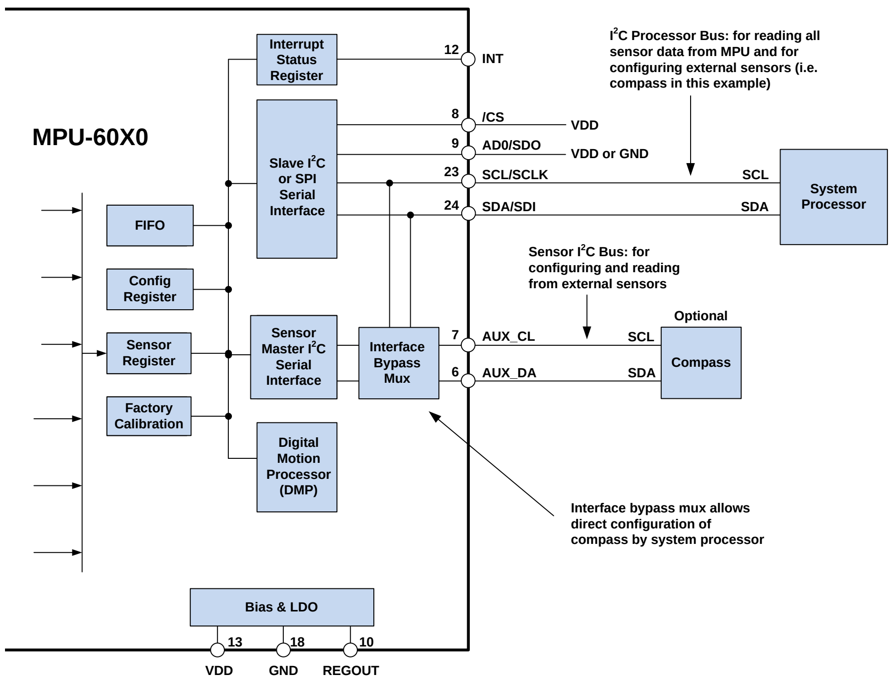
When the value of the self-test response is within the min/max limits of the product specification, the part has passed self test. When the self-test response exceeds the min/max values, the part is deemed to have failed self-test. Code for operating self test code is included within the MotionApps software provided by InvenSense.

7.13 MPU-60X0 Solution for 9-axis Sensor Fusion Using I^2C Interface

In the figure below, the system processor is an I^2C master to the MPU-60X0. In addition, the MPU-60X0 is an I^2C master to the optional external compass sensor. The MPU-60X0 has limited capabilities as an I^2C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors. The MPU-60X0 has an interface bypass multiplexer, which connects the system processor I^2C bus pins 23 and 24 (SDA and SCL) directly to the auxiliary sensor I^2C bus pins 6 and 7 (AUX_DA and AUX_CL).

Once the auxiliary sensors have been configured by the system processor, the interface bypass multiplexer should be disabled so that the MPU-60X0 auxiliary I^2C master can take control of the sensor I^2C bus and gather data from the auxiliary sensors.

For further information regarding I^2C master control, please refer to Section 10.



7.14 MPU-6000 Using SPI Interface

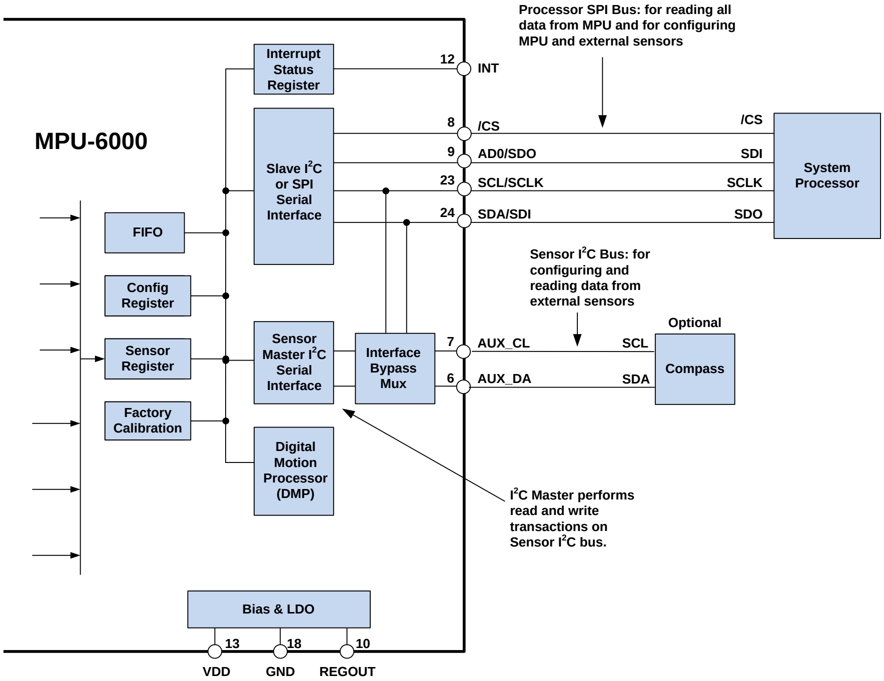
In the figure below, the system processor is an SPI master to the MPU-6000. Pins 8, 9, 23, and 24 are used to support the /CS, SDO, SCLK, and SDI signals for SPI communications. Because these SPI pins are shared with the I^{2}C slave pins (9, 23 and 24), the system processor cannot access the auxiliary I^{2}C bus through the interface bypass multiplexer, which connects the processor I^{2}C interface pins to the sensor I^{2}C interface pins.

Since the MPU-6000 has limited capabilities as an I^{2}C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors, another method must be used for programming the sensors on the auxiliary sensor I^{2}C bus pins 6 and 7 (AUX_DA and AUX_CL).

When using SPI communications between the MPU-6000 and the system processor, configuration of devices on the auxiliary I^{2}C sensor bus can be achieved by using I^{2}C Slaves 0-4 to perform read and write transactions on any device and register on the auxiliary I^{2}C bus. The I^{2}C Slave 4 interface can be used to perform only single byte read and write transactions.

Once the external sensors have been configured, the MPU-6000 can perform single or multi-byte reads using the sensor I^{2}C bus. The read results from the Slave 0-3 controllers can be written to the FIFO buffer as well as to the external sensor registers.

For further information regarding the control of the MPU-60X0's auxiliary I^{2}C interface, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.



7.15 Internal Clock Generation

The MPU-60X0 has a flexible clocking scheme, allowing a variety of internal or external clock sources to be used for the internal synchronous circuitry. This synchronous circuitry includes the signal conditioning and ADCs, the DMP, and various control circuits and registers. An on-chip PLL provides flexibility in the allowable inputs for generating this clock.

Allowable internal sources for generating the internal clock are:

- An internal relaxation oscillator
- Any of the X, Y, or Z gyros (MEMS oscillators with a variation of ±1% over temperature)

Allowable external clocking sources are:

- 32.768kHz square wave
- 19.2MHz square wave

Selection of the source for generating the internal synchronous clock depends on the availability of external sources and the requirements for power consumption and clock accuracy. These requirements will most likely vary by mode of operation. For example, in one mode, where the biggest concern is power consumption, the user may wish to operate the Digital Motion Processor of the MPU-60X0 to process accelerometer data, while keeping the gyros off. In this case, the internal relaxation oscillator is a good clock choice. However, in another mode, where the gyros are active, selecting the gyros as the clock source provides for a more accurate clock source.

Clock accuracy is important, since timing errors directly affect the distance and angle calculations performed by the Digital Motion Processor (and by extension, by any processor).

There are also start-up conditions to consider. When the MPU-60X0 first starts up, the device uses its internal clock until programmed to operate from another source. This allows the user, for example, to wait for the MEMS oscillators to stabilize before they are selected as the clock source.

7.16 Sensor Data Registers

The sensor data registers contain the latest gyro, accelerometer, auxiliary sensor, and temperature measurement data. They are read-only registers, and are accessed via the serial interface. Data from these registers may be read anytime. However, the interrupt function may be used to determine when new data is available.

For a table of interrupt sources please refer to Section 8.

7.17 FIFO

The MPU-60X0 contains a 1024-byte FIFO register that is accessible via the Serial Interface. The FIFO configuration register determines which data is written into the FIFO. Possible choices include gyro data, accelerometer data, temperature readings, auxiliary sensor readings, and FSYNC input. A FIFO counter keeps track of how many bytes of valid data are contained in the FIFO. The FIFO register supports burst reads. The interrupt function may be used to determine when new data is available.

For further information regarding the FIFO, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

7.18 Interrupts

Interrupt functionality is configured via the Interrupt Configuration register. Items that are configurable include the INT pin configuration, the interrupt latching and clearing method, and triggers for the interrupt. Items that can trigger an interrupt are (1) Clock generator locked to new reference oscillator (used when switching clock sources); (2) new data is available to be read (from the FIFO and Data registers); (3) accelerometer event interrupts; and (4) the MPU-60X0 did not receive an acknowledge from an auxiliary sensor on the secondary I^2C bus. The interrupt status can be read from the Interrupt Status register.

For further information regarding interrupts, please refer to the MPU-60X0 Register Map and Register Descriptions document.

For information regarding the MPU-60X0's accelerometer event interrupts, please refer to Section 8.

7.19 Digital-Output Temperature Sensor

An on-chip temperature sensor and ADC are used to measure the MPU-60X0 die temperature. The readings from the ADC can be read from the FIFO or the Sensor Data registers.

7.20 Bias and LDO

The bias and LDO section generates the internal supply and the reference voltages and currents required by the MPU-60X0. Its two inputs are an unregulated VDD of 2.375 to 3.46V and a VLOGIC logic reference supply voltage of 1.71V to VDD (MPU-6050 only). The LDO output is bypassed by a capacitor at REGOUT. For further details on the capacitor, please refer to the Bill of Materials for External Components (Section 7.3).

7.21 Charge Pump

An on-board charge pump generates the high voltage required for the MEMS oscillators. Its output is bypassed by a capacitor at CPOUT. For further details on the capacitor, please refer to the Bill of Materials for External Components (Section 7.3).

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8 Programmable Interrupts

The MPU-60X0 has a programmable interrupt system which can generate an interrupt signal on the INT pin. Status flags indicate the source of an interrupt. Interrupt sources may be enabled and disabled individually.

Table of Interrupt Sources

Interrupt Name	Module
FIFO Overflow	FIFO
Data Ready	Sensor Registers
I^{2}C Master errors: Lost Arbitration, NACKs	I^{2}C Master
I^{2}C Slave 4	I^{2}C Master

For information regarding the interrupt enable/disable registers and flag registers, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document. Some interrupt sources are explained below.

9 Digital Interface

9.1 I^{2}C and SPI (MPU-6000 only) Serial Interfaces

The internal registers and memory of the MPU-6000/MPU-6050 can be accessed using either I^{2}C at 400 kHz or SPI at 1MHz (MPU-6000 only). SPI operates in four-wire mode.

Serial Interface

Pin Number	MPU-6000	MPU-6050	Pin Name	Pin Description
8	Y		/CS	SPI chip select (0=SPI enable)
8		Y	VLOGIC	Digital I/O supply voltage. VLOGIC must be ≤ VDD at all times.
9	Y		AD0 / SDO	I^{2}C Slave Address LSB (AD0); SPI serial data output (SDO)
9		Y	AD0	I^{2}C Slave Address LSB
23	Y		SCL / SCLK	I^{2}C serial clock (SCL); SPI serial clock (SCLK)
23		Y	SCL	I^{2}C serial clock
24	Y		SDA / SDI	I^{2}C serial data (SDA); SPI serial data input (SDI)
24		Y	SDA	I^{2}C serial data

Note:

To prevent switching into I^{2}C mode when using SPI (MPU-6000), the I^{2}C interface should be disabled by setting the *I2C_IF_DIS* configuration bit. Setting this bit should be performed immediately after waiting for the time specified by the "Start-Up Time for Register Read/Write" in Section 6.3.

For further information regarding the *I2C_IF_DIS* bit, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

9.2 I^{2}C Interface

I^{2}C is a two-wire interface comprised of the signals serial data (SDA) and serial clock (SCL). In general, the lines are open-drain and bi-directional. In a generalized I^{2}C interface implementation, attached devices can be a master or a slave. The master device puts the slave address on the bus, and the slave device with the matching address acknowledges the master.

The MPU-60X0 always operates as a slave device when communicating to the system processor, which thus acts as the master. SDA and SCL lines typically need pull-up resistors to VDD. The maximum bus speed is 400 kHz.

The slave address of the MPU-60X0 is b110100X which is 7 bits long. The LSB bit of the 7 bit address is determined by the logic level on pin AD0. This allows two MPU-60X0s to be connected to the same I^{2}C bus. When used in this configuration, the address of the one of the devices should be b1101000 (pin AD0 is logic low) and the address of the other should be b1101001 (pin AD0 is logic high).

9.3 I^{2}C Communications Protocol

START (S) and STOP (P) Conditions

Communication on the I^{2}C bus starts when the master puts the START condition (S) on the bus, which is defined as a HIGH-to-LOW transition of the SDA line while SCL line is HIGH (see figure below). The bus is considered to be busy until the master puts a STOP condition (P) on the bus, which is defined as a LOW to HIGH transition on the SDA line while SCL is HIGH (see figure below).

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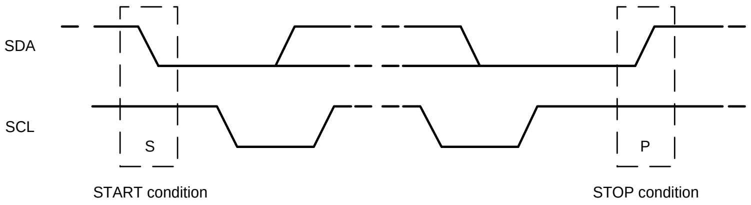
Additionally, the bus remains busy if a repeated START (Sr) is generated instead of a STOP condition.

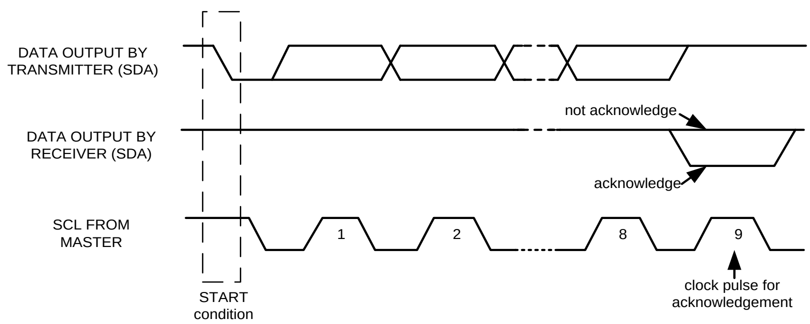


START and STOP Conditions

Data Format / Acknowledge

I^{2}C data bytes are defined to be 8-bits long. There is no restriction to the number of bytes transmitted per data transfer. Each byte transferred must be followed by an acknowledge (ACK) signal. The clock for the acknowledge signal is generated by the master, while the receiver generates the actual acknowledge signal by pulling down SDA and holding it low during the HIGH portion of the acknowledge clock pulse.

If a slave is busy and cannot transmit or receive another byte of data until some other task has been performed, it can hold SCL LOW, thus forcing the master into a wait state. Normal data transfer resumes when the slave is ready, and releases the clock line (refer to the following figure).



Acknowledge on the I^{2}C Bus

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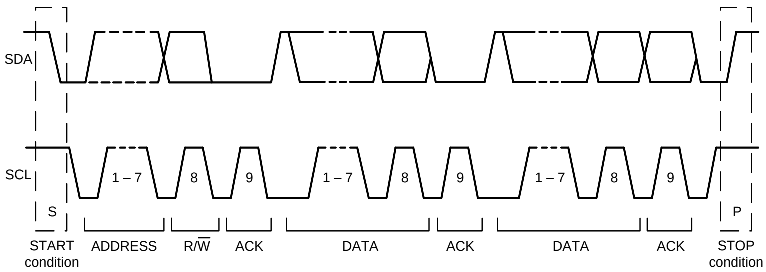
Communications

After beginning communications with the START condition (S), the master sends a 7-bit slave address followed by an 8th bit, the read/write bit. The read/write bit indicates whether the master is receiving data from or is writing to the slave device. Then, the master releases the SDA line and waits for the acknowledge signal (ACK) from the slave device. Each byte transferred must be followed by an acknowledge bit. To acknowledge, the slave device pulls the SDA line LOW and keeps it LOW for the high period of the SCL line. Data transmission is always terminated by the master with a STOP condition (P), thus freeing the communications line. However, the master can generate a repeated START condition (Sr), and address another slave without first generating a STOP condition (P). A LOW to HIGH transition on the SDA line while SCL is HIGH defines the stop condition. All SDA changes should take place when SCL is low, with the exception of start and stop conditions.



Complete I^{2}C Data Transfer

To write the internal MPU-60X0 registers, the master transmits the start condition (S), followed by the I^{2}C address and the write bit (0). At the 9th clock cycle (when the clock is high), the MPU-60X0 acknowledges the transfer. Then the master puts the register address (RA) on the bus. After the MPU-60X0 acknowledges the reception of the register address, the master puts the register data onto the bus. This is followed by the ACK signal, and data transfer may be concluded by the stop condition (P). To write multiple bytes after the last ACK signal, the master can continue outputting data rather than transmitting a stop signal. In this case, the MPU-60X0 automatically increments the register address and loads the data to the appropriate register. The following figures show single and two-byte write sequences.

Single-Byte Write Sequence

Master	S	AD+W		RA		DATA		P
Slave			ACK		ACK		ACK	

Burst Write Sequence

Master	S	AD+W		RA		DATA		DATA		P
Slave			ACK		ACK		ACK		ACK	

To read the internal MPU-60X0 registers, the master sends a start condition, followed by the I^2C address and a write bit, and then the register address that is going to be read. Upon receiving the ACK signal from the MPU-60X0, the master transmits a start signal followed by the slave address and read bit. As a result, the MPU-60X0 sends an ACK signal and the data. The communication ends with a not acknowledge (NACK) signal and a stop bit from master. The NACK condition is defined such that the SDA line remains high at the 9^{th} clock cycle. The following figures show single and two-byte read sequences.

Single-Byte Read Sequence

Master	S	AD+W		RA		S	AD+R			NACK	P
Slave			ACK		ACK			ACK	DATA		

Burst Read Sequence

Master	S	AD+W		RA		S	AD+R			ACK		NACK	P
Slave			ACK		ACK			ACK	DATA		DATA		

9.4 I^2C Terms

Signal	Description
S	Start Condition: SDA goes from high to low while SCL is high
AD	Slave I^2C address
W	Write bit (0)
R	Read bit (1)
ACK	Acknowledge: SDA line is low while the SCL line is high at the 9^{th} clock cycle
NACK	Not-Acknowledge: SDA line stays high at the 9^{th} clock cycle
RA	MPU-60X0 internal register address
DATA	Transmit or received data
P	Stop condition: SDA going from low to high while SCL is high

9.5 SPI Interface (MPU-6000 only)

SPI is a 4-wire synchronous serial interface that uses two control lines and two data lines. The MPU-6000 always operates as a Slave device during standard Master-Slave SPI operation.

With respect to the Master, the Serial Clock output (SCLK), the Serial Data Output (SDO) and the Serial Data Input (SDI) are shared among the Slave devices. Each SPI slave device requires its own Chip Select (/CS) line from the master.

/CS goes low (active) at the start of transmission and goes back high (inactive) at the end. Only one /CS line is active at a time, ensuring that only one slave is selected at any given time. The /CS lines of the non-selected slave devices are held high, causing their SDO lines to remain in a high-impedance (high-z) state so that they do not interfere with any active devices.

SPI Operational Features

1. Data is delivered MSB first and LSB last
2. Data is latched on the rising edge of SCLK
3. Data should be transitioned on the falling edge of SCLK
4. The maximum frequency of SCLK is 1MHz
5. SPI read and write operations are completed in 16 or more clock cycles (two or more bytes). The first byte contains the SPI Address, and the following byte(s) contain(s) the SPI data. The first bit of the first byte contains the Read/Write bit and indicates the Read (1) or Write (0) operation. The following 7 bits contain the Register Address. In cases of multiple-byte Read/Writes, data is two or more bytes:

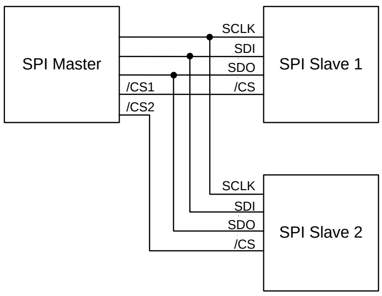
SPI Address format

MSB							**LSB**
R/W	A6	A5	A4	A3	A2	A1	A0

SPI Data format

MSB							**LSB**
D7	D6	D5	D4	D3	D2	D1	D0

6. Supports Single or Burst Read/Writes.



Typical SPI Master / Slave Configuration

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10 Serial Interface Considerations (MPU-6050)

10.1 MPU-6050 Supported Interfaces

The MPU-6050 supports I^2C communications on both its primary (microprocessor) serial interface and its auxiliary interface.

10.2 Logic Levels

The MPU-6050's I/O logic levels are set to be VLOGIC, as shown in the table below. AUX_VDDIO must be set to 0.

I/O Logic Levels vs. *AUX_VDDIO*

AUX_VDDIO	**MICROPROCESSOR LOGIC LEVELS** (Pins: SDA, SCL, AD0, CLKIN, INT)	**AUXILLARY LOGIC LEVELS** (Pins: AUX_DA, AUX_CL)
0	VLOGIC	VLOGIC

Note: The power-on-reset value for *AUX_VDDIO* is 0.

When *AUX_VDDIO* is set to 0 (its power-on-reset value), VLOGIC is the power supply voltage for both the microprocessor system bus and the auxiliary I^2C bus, as shown in the figure of Section 10.3.

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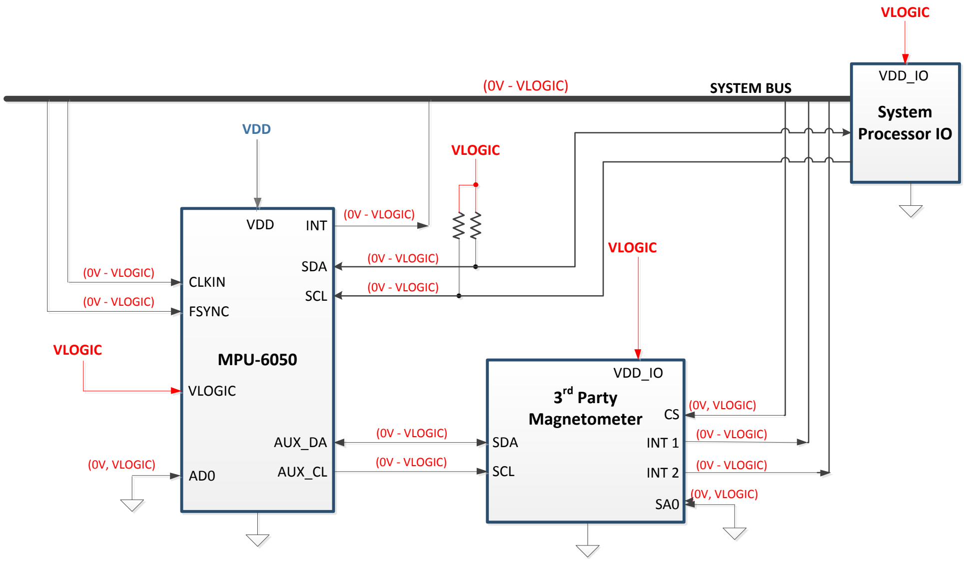
10.3 Logic Levels Diagram for AUX_*VDDIO* = 0

The figure below depicts a sample circuit with a third party magnetometer attached to the auxiliary I^2C bus. It shows logic levels and voltage connections for *AUX_VDDIO* = 0. Note: Actual configuration will depend on the auxiliary sensors used.



I/O Levels and Connections for *AUX_VDDIO* = 0

Notes:

1. AUX_VDDIO determines the IO voltage levels of AUX_DA and AUX_CL (0 = set output levels relative to VLOGIC)
2. All other MPU-6050 logic IOs are referenced to VLOGIC.

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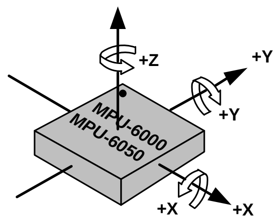
11 Assembly

This section provides general guidelines for assembling InvenSense Micro Electro-Mechanical Systems (MEMS) gyros packaged in Quad Flat No leads package (QFN) surface mount integrated circuits.

11.1 Orientation of Axes

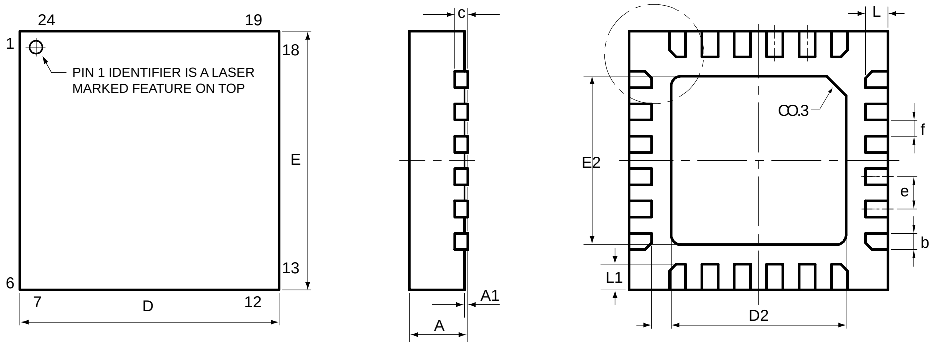
The diagram below shows the orientation of the axes of sensitivity and the polarity of rotation. Note the pin 1 identifier (•) in the figure.

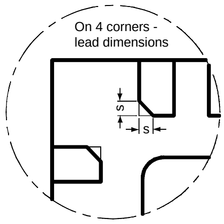


Orientation of Axes of Sensitivity and Polarity of Rotation

11.2 Package Dimensions

24 Lead QFN (4x4x0.9) mm NiPdAu Lead-frame finish

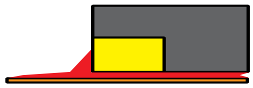




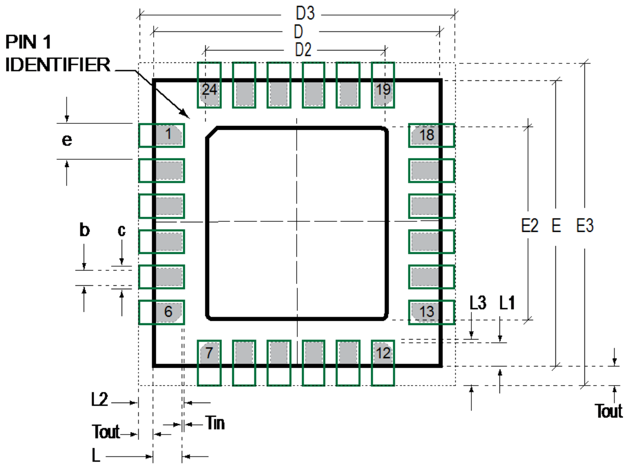
SYMBOLS	DIMENSIONS IN MILLIMETERS		
	MIN	NOM	MAX
A	0.85	0.90	0.95
A1	0.00	0.02	0.05
b	0.18	0.25	0.30
c	---	0.20 REF	---
D	3.90	4.00	4.10
D2	2.65	2.70	2.75
E	3.90	4.00	4.10
E2	2.55	2.60	2.65
e	---	0.50	---
f (e-b)	---	0.25	---
K	0.25	0.30	0.35
L	0.30	0.35	0.40
L1	0.35	0.40	0.45
s	0.05	---	0.15

11.3 PCB Design Guidelines

The Pad Diagram using a JEDEC type extension with solder rising on the outer edge is shown below. The Pad Dimensions Table shows pad sizing (mean dimensions) recommended for the MPU-60X0 product.



JEDEC type extension with solder rising on outer edge



PCB Layout Diagram

SYMBOLS	DIMENSIONS IN MILLIMETERS	NOM
	Nominal Package I/O Pad Dimensions	
e	Pad Pitch	0.50
b	Pad Width	0.25
L	Pad Length	0.35
L1	Pad Length	0.40
D	Package Width	4.00
E	Package Length	4.00
D2	Exposed Pad Width	2.70
E2	Exposed Pad Length	2.60
	I/O Land Design Dimensions (Guidelines)	
D3	I/O Pad Extent Width	4.80
E3	I/O Pad Extent Length	4.80
c	Land Width	0.35
Tout	Outward Extension	0.40
Tin	Inward Extension	0.05
L2	Land Length	0.80
L3	Land Length	0.85

PCB Dimensions Table (for PCB Lay-out Diagram)

11.4 Assembly Precautions

11.4.1 Gyroscope Surface Mount Guidelines

InvenSense MEMS Gyros sense rate of rotation. In addition, gyroscopes sense mechanical stress coming from the printed circuit board (PCB). This PCB stress can be minimized by adhering to certain design rules:

When using MEMS gyroscope components in plastic packages, PCB mounting and assembly can cause package stress. This package stress in turn can affect the output offset and its value over a wide range of temperatures. This stress is caused by the mismatch between the Coefficient of Linear Thermal Expansion (CTE) of the package material and the PCB. Care must be taken to avoid package stress due to mounting.

Traces connected to pads should be as symmetric as possible. Maximizing symmetry and balance for pad connection will help component self alignment and will lead to better control of solder paste reduction after reflow.

Any material used in the surface mount assembly process of the MEMS gyroscope should be free of restricted RoHS elements or compounds. Pb-free solders should be used for assembly.

11.4.2 Exposed Die Pad Precautions

The MPU-60X0 has very low active and standby current consumption. The exposed die pad is not required for heat sinking, and should not be soldered to the PCB. Failure to adhere to this rule can induce performance changes due to package thermo-mechanical stress. There is no electrical connection between the pad and the CMOS.

11.4.3 Trace Routing

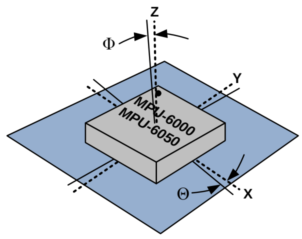
Routing traces or vias under the gyro package such that they run under the exposed die pad is prohibited. Routed active signals may harmonically couple with the gyro MEMS devices, compromising gyro response. These devices are designed with the drive frequencies as follows: X = 33±3Khz, Y = 30±3Khz, and Z=27±3Khz. To avoid harmonic coupling don't route active signals in non-shielded signal planes directly below, or above the gyro package. Note: For best performance, design a ground plane under the e-pad to reduce PCB signal noise from the board on which the gyro device is mounted. If the gyro device is stacked under an adjacent PCB board, design a ground plane directly above the gyro device to shield active signals from the adjacent PCB board.

11.4.4 Component Placement

Do not place large insertion components such as keyboard or similar buttons, connectors, or shielding boxes at a distance of less than 6 mm from the MEMS gyro. Maintain generally accepted industry design practices for component placement near the MPU-60X0 to prevent noise coupling and thermo-mechanical stress.

11.4.5 PCB Mounting and Cross-Axis Sensitivity

Orientation errors of the gyroscope and accelerometer mounted to the printed circuit board can cause cross-axis sensitivity in which one gyro or accel responds to rotation or acceleration about another axis, respectively. For example, the X-axis gyroscope may respond to rotation about the Y or Z axes. The orientation mounting errors are illustrated in the figure below.



Package Gyro & Accel Axes (– – –) Relative to PCB Axes (——) with Orientation Errors (Θ and Φ)

The table below shows the cross-axis sensitivity as a percentage of the gyroscope or accelerometer's sensitivity for a given orientation error, respectively.

Cross-Axis Sensitivity vs. Orientation Error

Orientation Error (θ or Φ)	Cross-Axis Sensitivity (sinθ or sinΦ)
0º	0%
0.5º	0.87%
1º	1.75%

The specifications for cross-axis sensitivity in Section 6.1 and Section 6.2 include the effect of the die orientation error with respect to the package.

11.4.6 MEMS Handling Instructions

MEMS (Micro Electro-Mechanical Systems) are a time-proven, robust technology used in hundreds of millions of consumer, automotive and industrial products. MEMS devices consist of microscopic moving mechanical structures. They differ from conventional IC products, even though they can be found in similar packages. Therefore, MEMS devices require different handling precautions than conventional ICs prior to mounting onto printed circuit boards (PCBs).

The MPU-60X0 has been qualified to a shock tolerance of 10,000*g*. InvenSense packages its gyroscopes as it deems proper for protection against normal handling and shipping. It recommends the following handling precautions to prevent potential damage.

- Do not drop individually packaged gyroscopes, or trays of gyroscopes onto hard surfaces. Components placed in trays could be subject to *g*-forces in excess of 10,000*g* if dropped.
- Printed circuit boards that incorporate mounted gyroscopes should not be separated by manually snapping apart. This could also create *g*-forces in excess of 10,000*g.*
- Do not clean MEMS gyroscopes in ultrasonic baths. Ultrasonic baths can induce MEMS damage if the bath energy causes excessive drive motion through resonant frequency coupling.

11.4.7 ESD Considerations

Establish and use ESD-safe handling precautions when unpacking and handling ESD-sensitive devices.

- Store ESD sensitive devices in ESD safe containers until ready for use. The Tape-and-Reel moisture-sealed bag is an ESD approved barrier. The best practice is to keep the units in the original moisture sealed bags until ready for assembly.

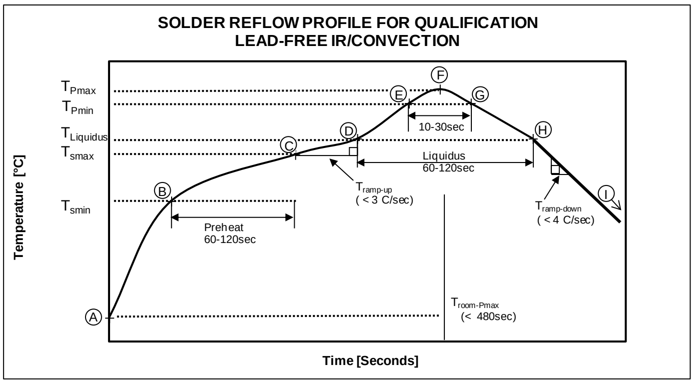
Restrict all device handling to ESD protected work areas that measure less than 200V static charge. Ensure that all workstations and personnel are properly grounded to prevent ESD.

11.4.8 Reflow Specification

Qualification Reflow: The MPU-60X0 was qualified in accordance with IPC/JEDEC J-STD-020D.1. This standard classifies proper packaging, storage and handling in order to avoid subsequent thermal and mechanical damage during the solder reflow attachment phase of PCB assembly.

The qualification preconditioning process specifies a sequence consisting of a bake cycle, a moisture soak cycle (in a temperature humidity oven), and three consecutive solder reflow cycles, followed by functional device testing.

The peak solder reflow classification temperature requirement for package qualification is (260 +5/-0°C) for lead-free soldering of components measuring less than 1.6 mm in thickness. The qualification profile and a table explaining the set-points are shown below:



Temperature Set Points Corresponding to Reflow Profile Above

Step	Setting	CONSTRAINTS		
		Temp (°C)	Time (sec)	Max. Rate (°C/sec)
A	T_{room}	25		
B	T_{Smin}	150		
C	T_{Smax}	200	$60 < t_{BC} < 120$	
D	$T_{Liquidus}$	217		$r_{(TLiquidus\text{-}TPmax)} < 3$
E	$T_{Pmin\ [255°C,\ 260°C]}$	255		$r_{(TLiquidus\text{-}TPmax)} < 3$
F	$T_{Pmax\ [260°C,\ 265°C]}$	260	$t_{AF} < 480$	$r_{(TLiquidus\text{-}TPmax)} < 3$
G	$T_{Pmin\ [255°C,\ 260°C]}$	255	$10 < t_{EG} < 30$	$r_{(TPmax\text{-}TLiquidus)} < 4$
H	$T_{Liquidus}$	217	$60 < t_{DH} < 120$	
I	T_{room}	25		

Notes: Customers must never exceed the Classification temperature (T_{Pmax} = 260°C).
All temperatures refer to the topside of the QFN package, as measured on the package body surface.

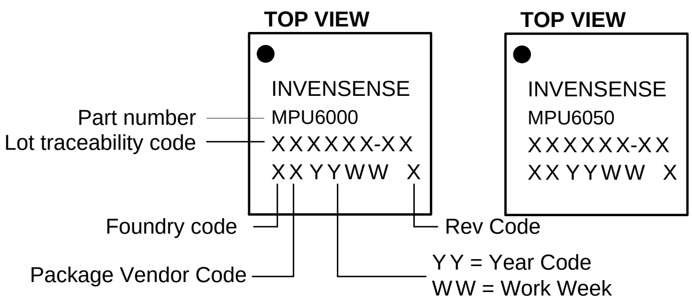
Production Reflow: Check the recommendations of your solder manufacturer. For optimum results, use lead-free solders that have lower specified temperature profiles (Tp_{max} ~ 235°C). Also use lower ramp-up and ramp-down rates than those used in the qualification profile. Never exceed the maximum conditions that we used for qualification, as these represent the maximum tolerable ratings for the device.

11.5 Storage Specifications

The storage specification of the MPU-60X0 conforms to IPC/JEDEC J-STD-020D.1 Moisture Sensitivity Level (MSL) 3.

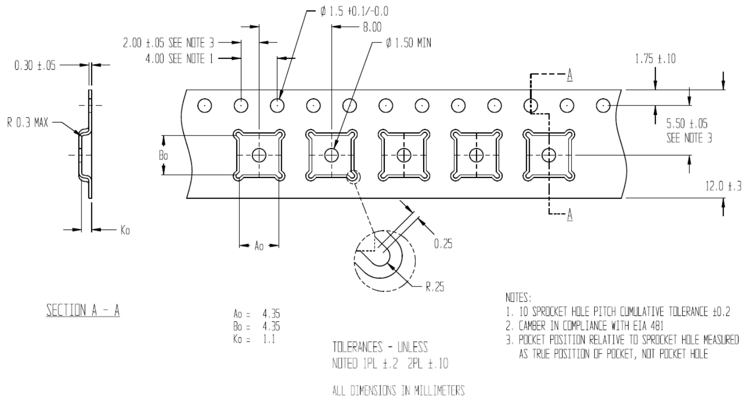
Calculated shelf-life in moisture-sealed bag	12 months -- Storage conditions: <40°C and <90% RH
After opening moisture-sealed bag	168 hours -- Storage conditions: ambient ≤30°C at 60%RH

11.6 Package Marking Specification

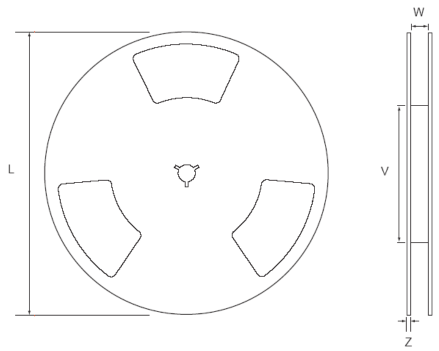


Package Marking Specification

11.7 Tape & Reel Specification



Tape Dimensions



Reel Outline Drawing

Reel Dimensions and Package Size

PACKAGE SIZE	REEL (mm)			
	L	V	W	Z
4x4	330	102	12.8	2.3

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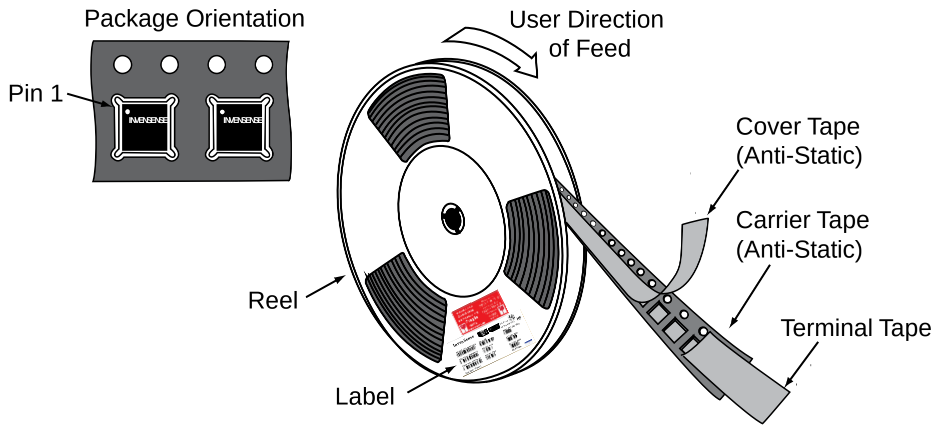

Tape and Reel Specification

Reel Specifications

Quantity Per Reel	**5,000**
Reels per Box	**1**
Boxes Per Carton (max)	**5**
Pcs/Carton (max)	**25,000**

11.8 Label

Barcode Label

Location of Label on Reel

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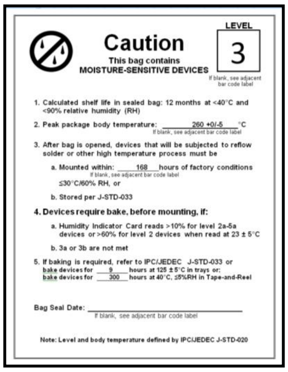
11.9 Packaging

REEL – with Barcode & Caution labels

Vacuum-Sealed Moisture Barrier Bag with ESD, MSL3, Caution, and Barcode Labels



Caution
This bag contains
MOISTURE-SENSITIVE DEVICES
LEVEL
3
If blank, see adjacent bar code label

1. Calculated shelf life in sealed bag: 12 months at <40°C and <90% relative humidity (RH)
2. Peak package body temperature: 260 +0/-5 °C
If blank, see adjacent bar code label
3. After bag is opened, devices that will be subjected to reflow solder or other high temperature process must be
a. Mounted within: 168 hours of factory conditions
If blank, see adjacent bar code label
≤30°C/60% RH, or
b. Stored per J-STD-033
4. Devices require bake, before mounting, if:
a. Humidity Indicator Card reads >10% for level 2a-5a devices or >60% for level 2 devices when read at 23 ± 5°C
b. 3a or 3b are not met
5. If baking is required, refer to IPC/JEDEC J-STD-033 or
bake devices for 9 hours at 125 ± 5°C in trays or;
bake devices for 300 hours at 40°C, ≤5%RH in Tape-and-Reel

Bag Seal Date: ______
If blank, see adjacent bar code label

Note: Level and body temperature defined by IPC/JEDEC J-STD-020

MSL3 Label

Caution Label

ESD Label

Inner Bubble Wrap

Pizza Box

Pizza Boxes Placed in Foam-Lined Shipper Box

Outer Shipper Label

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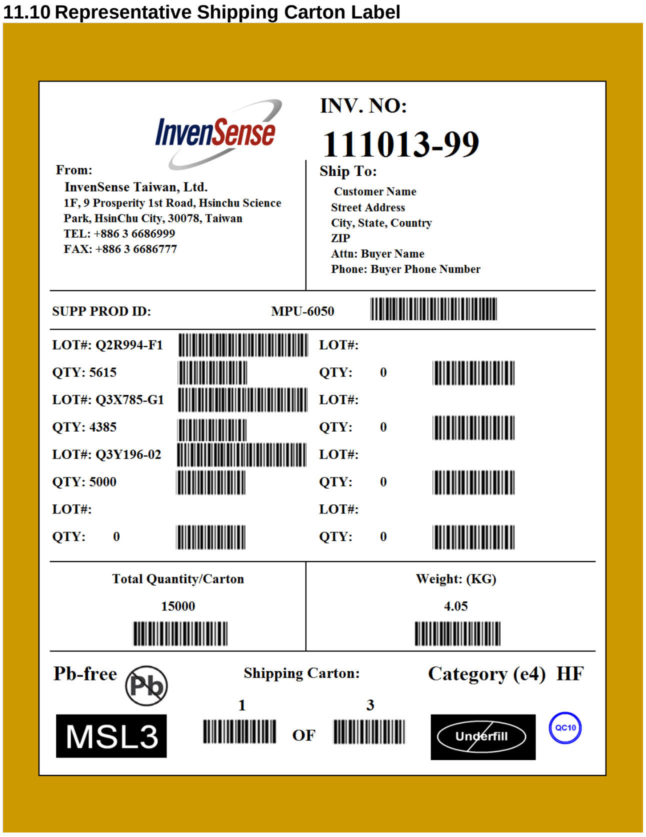
11.10 Representative Shipping Carton Label



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12 Reliability

12.1 Qualification Test Policy

InvenSense's products complete a Qualification Test Plan before being released to production. The Qualification Test Plan for the MPU-60X0 followed the JESD47I Standards, "Stress-Test-Driven Qualification of Integrated Circuits," with the individual tests described below.

12.2 Qualification Test Plan

Accelerated Life Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(HTOL/LFR) High Temperature Operating Life	JEDEC JESD22-A108D, Dynamic, 3.63V biased, Tj>125°C [read-points 168, 500, 1000 hours]	3	77	(0/1)
(HAST) Highly Accelerated Stress Test (1)	JEDEC JESD22-A118A Condition A, 130°C, 85%RH, 33.3 psia. unbiased, [read-point 96 hours]	3	77	(0/1)
(HTS) High Temperature Storage Life	JEDEC JESD22-A103D, Cond. A, 125°C Non-Bias Bake [read-points 168, 500, 1000 hours]	3	77	(0/1)

Device Component Level Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(ESD-HBM) ESD-Human Body Model	JEDEC JS-001-2012, (2KV)	1	3	(0/1)
(ESD-MM) ESD-Machine Model	JEDEC JESD22-A115C, (250V)	1	3	(0/1)
(LU) Latch Up	JEDEC JESD-78D Class II (2), 125°C; ±100mA	1	6	(0/1)
(MS) Mechanical Shock	JEDEC JESD22-B104C, Mil-Std-883, Method 2002.5, Cond. E, 10,000*g's*, 0.2ms, ±X, Y, Z – 6 directions, 5 times/direction	3	5	(0/1)
(VIB) Vibration	JEDEC JESD22-B103B, Variable Frequency (random), Cond. B, 5-500Hz, X, Y, Z – 4 times/direction	3	5	(0/1)
(TC) Temperature Cycling (1)	JEDEC JESD22-A104D Condition G [-40°C to +125°C], Soak Mode 2 [5'], 1000 cycles	3	77	(0/1)

Board Level Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(BMS) Board Mechanical Shock	JEDEC JESD22-B104C,Mil-Std-883, Method 2002.5, Cond. E, 10000*g's*, 0.2ms, +-X, Y, Z – 6 directions, 5 times/direction	1	5	(0/1)
(BTC) Board Temperature Cycling (1)	JEDEC JESD22-A104D Condition G [-40°C to +125°C], Soak mode 2 [5'], 1000 cycles	1	40	(0/1)

(1) Tests are preceded by MSL3 Preconditioning in accordance with JEDEC JESD22-A113F

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13 Environmental Compliance

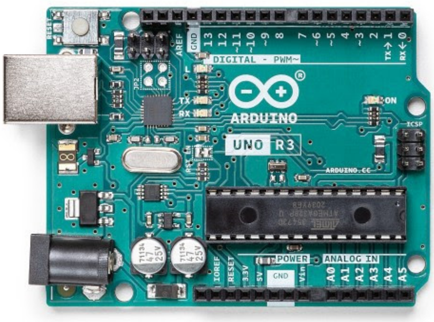
The MPU-6000/MPU-6050 is RoHS and Green compliant.

The MPU-6000/MPU-6050 is in full environmental compliance as evidenced in report HS-MPU-6000, Materials Declaration Data Sheet.

Environmental Declaration Disclaimer:

InvenSense believes this environmental information to be correct but cannot guarantee accuracy or completeness. Conformity documents for the above component constitutes are on file. InvenSense subcontracts manufacturing and the information contained herein is based on data received from vendors and suppliers, which has not been validated by InvenSense.

Product Reference Manual
SKU: A000066



Description

The Arduino UNO R3 is the perfect board to get familiar with electronics and coding. This versatile microcontroller is equipped with the well-known ATmega328P and the ATMega 16U2 Processor.
This board will give you a great first experience within the world of Arduino.

Target areas:

Maker, introduction, industries

Features

- **ATMega328P** Processor
  - **Memory**
    - AVR CPU at up to 16 MHz
    - 32KB Flash
    - 2KB SRAM
    - 1KB EEPROM
  - **Security**
    - Power On Reset (POR)
    - Brown Out Detection (BOD)
  - **Peripherals**
    - 2x 8-bit Timer/Counter with a dedicated period register and compare channels
    - 1x 16-bit Timer/Counter with a dedicated period register, input capture and compare channels
    - 1x USART with fractional baud rate generator and start-of-frame detection
    - 1x controller/peripheral Serial Peripheral Interface (SPI)
    - 1x Dual mode controller/peripheral I2C
    - 1x Analog Comparator (AC) with a scalable reference input
    - Watchdog Timer with separate on-chip oscillator
    - Six PWM channels
    - Interrupt and wake-up on pin change
  - **ATMega16U2 Processor**
    - 8-bit AVR® RISC-based microcontroller
  - **Memory**
    - 16 KB ISP Flash
    - 512B EEPROM
    - 512B SRAM
    - debugWIRE interface for on-chip debugging and programming
  - **Power**
    - 2.7-5.5 volts

CONTENTS

1 The Board

1.1 Application Examples

The UNO board is the flagship product of Arduino. Regardless if you are new to the world of electronics or will use the UNO as a tool for education purposes or industry-related tasks.

First entry to electronics: If this is your first project within coding and electronics, get started with our most used and documented board; Arduino UNO. It is equipped with the well-known ATmega328P processor, 14 digital input/output pins, 6 analog inputs, USB connections, ICSP header and reset button. This board includes everything you will need for a great first experience with Arduino.

Industry-standard development board: Using the Arduino UNO board in industries, there are a range of companies using the UNO board as the brain for their PLC's.

Education purposes: Although the UNO board has been with us for about ten years, it is still widely used for various education purposes and scientific projects. The board's high standard and top quality performance makes it a great resource to capture real time from sensors and to trigger complex laboratory equipment to mention a few examples.

1.2 Related Products

- Starter Kit
- Tinkerkit Braccio Robot
- Example

2 Ratings

2.1 Recommended Operating Conditions

Symbol	Description	Min	Max
	Conservative thermal limits for the whole board:	-40 °C (-40°F)	85 °C (185°F)

NOTE: In extreme temperatures, EEPROM, voltage regulator, and the crystal oscillator, might not work as expected due to the extreme temperature conditions

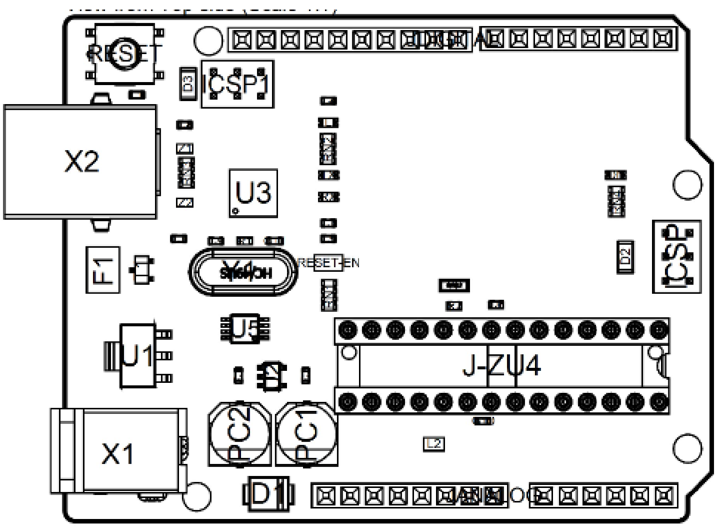
2.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
VINMax	Maximum input voltage from VIN pad	6	-	20	V
VUSBMax	Maximum input voltage from USB connector		-	5.5	V
PMax	Maximum Power Consumption	-	-	xx	mA

3 Functional Overview

3.1 Board Topology

Top view



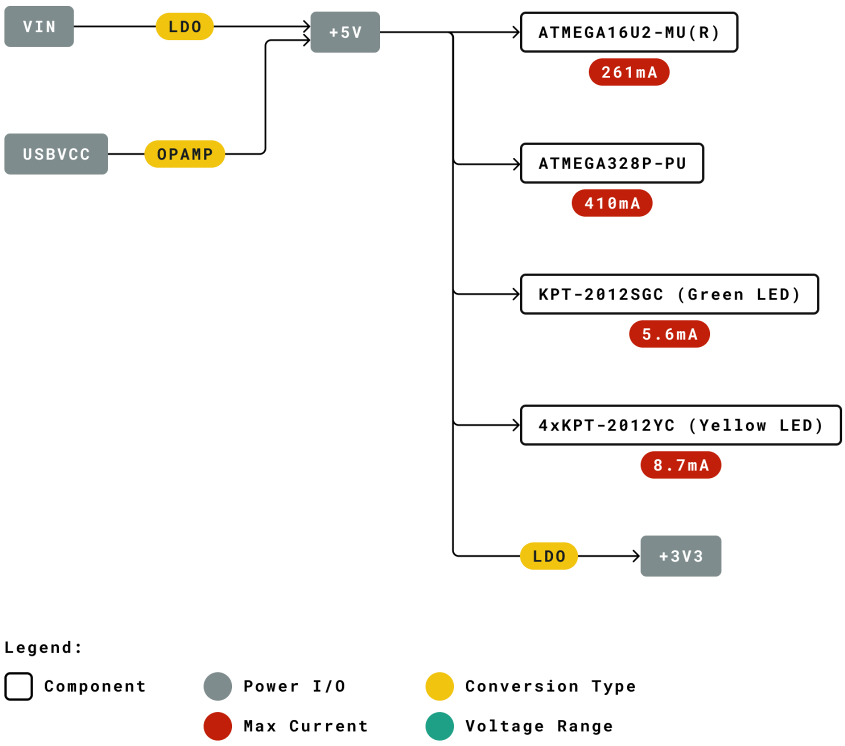
Board topology

Ref.	Description	Ref.	Description
X1	Power jack 2.1x5.5mm	U1	SPX1117M3-L-5 Regulator
X2	USB B Connector	U3	ATMEGA16U2 Module
PC1	EEE-1EA470WP 25V SMD Capacitor	U5	LMV358LIST-A.9 IC
PC2	EEE-1EA470WP 25V SMD Capacitor	F1	Chip Capacitor, High Density
D1	CGRA4007-G Rectifier	ICSP	Pin header connector (through hole 6)
J-ZU4	ATMEGA328P Module	ICSP1	Pin header connector (through hole 6)
Y1	ECS-160-20-4X-DU Oscillator		

3.2 Processor

The Main Processor is a ATmega328P running at up tp 20 MHz. Most of its pins are connected to the external headers, however some are reserved for internal communication with the USB Bridge coprocessor.

3.3 Power Tree



Power tree

4 Board Operation

4.1 Getting Started - IDE

If you want to program your Arduino UNO while offline you need to install the Arduino Desktop IDE [1] To connect the Arduino UNO to your computer, you'll need a Micro-B USB cable. This also provides power to the board, as indicated by the LED.

4.2 Getting Started - Arduino Web Editor

All Arduino boards, including this one, work out-of-the-box on the Arduino Web Editor [2], by just installing a simple plugin.

The Arduino Web Editor is hosted online, therefore it will always be up-to-date with the latest features and support for all boards. Follow **[3]** to start coding on the browser and upload your sketches onto your board.

4.3 Getting Started - Arduino IoT Cloud

All Arduino IoT enabled products are supported on Arduino IoT Cloud which allows you to Log, graph and analyze sensor data, trigger events, and automate your home or business.

4.4 Sample Sketches

Sample sketches for the Arduino XXX can be found either in the "Examples" menu in the Arduino IDE or in the "Documentation" section of the Arduino Pro website [4]

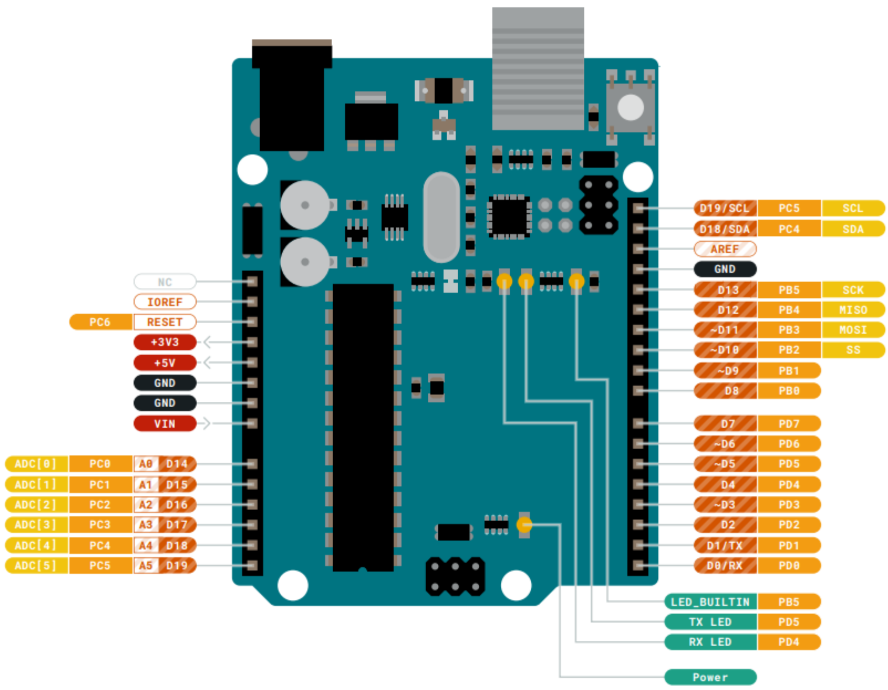
4.5 Online Resources

Now that you have gone through the basics of what you can do with the board you can explore the endless possibilities it provides by checking exciting projects on ProjectHub **[5]**, the Arduino Library Reference **[6]** and the online store **[7]** where you will be able to complement your board with sensors, actuators and more

4.6 Board Recovery

All Arduino boards have a built-in bootloader which allows flashing the board via USB. In case a sketch locks up the processor and the board is not reachable anymore via USB it is possible to enter bootloader mode by double-tapping the reset button right after power up.

5 Connector Pinouts



Pinout

5.1 JANALOG

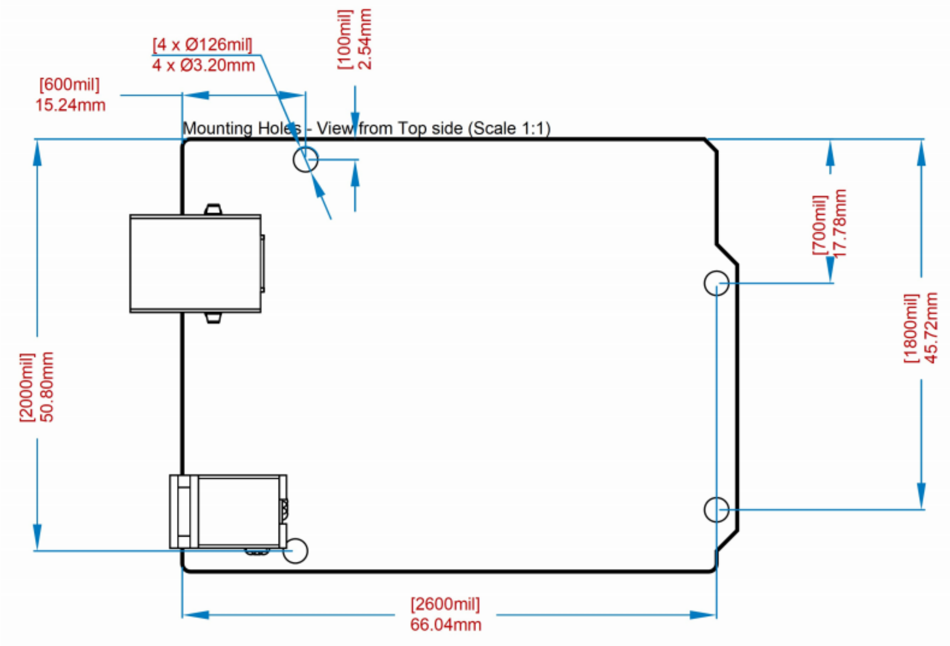
Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog/GPIO	Analog input 0 /GPIO
10	A1	Analog/GPIO	Analog input 1 /GPIO
11	A2	Analog/GPIO	Analog input 2 /GPIO
12	A3	Analog/GPIO	Analog input 3 /GPIO
13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

5.2 JDIGITAL

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 1/GPIO
3	D2	Digital/GPIO	Digital pin 2/GPIO
4	D3	Digital/GPIO	Digital pin 3/GPIO
5	D4	Digital/GPIO	Digital pin 4/GPIO
6	D5	Digital/GPIO	Digital pin 5/GPIO
7	D6	Digital/GPIO	Digital pin 6/GPIO
8	D7	Digital/GPIO	Digital pin 7/GPIO
9	D8	Digital/GPIO	Digital pin 8/GPIO
10	D9	Digital/GPIO	Digital pin 9/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Data line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

5.3 Mechanical Information

5.4 Board Outline & Mounting Holes



Board outline

6 Certifications

6.1 Declaration of Conformity CE DoC (EU)

We declare under our sole responsibility that the products above are in conformity with the essential requirements of the following EU Directives and therefore qualify for free movement within markets comprising the European Union (EU) and European Economic Area (EEA).

ROHS 2 Directive 2011/65/EU	
Conforms to:	EN50581:2012
Directive 2014/35/EU. (LVD)	
Conforms to:	EN 60950-1:2006/A11:2009/A1:2010/A12:2011/AC:2011
Directive 2004/40/EC & 2008/46/EC & 2013/35/EU, EMF	
Conforms to:	EN 62311:2008

6.2 Declaration of Conformity to EU RoHS & REACH 211 01/19/2021

Arduino boards are in compliance with RoHS 2 Directive 2011/65/EU of the European Parliament and RoHS 3 Directive 2015/863/EU of the Council of 4 June 2015 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Substance	Maximum limit (ppm)
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000
Bis(2-Ethylhexyl} phthalate (DEHP)	1000
Benzyl butyl phthalate (BBP)	1000
Dibutyl phthalate (DBP)	1000
Diisobutyl phthalate (DIBP)	1000

Exemptions: No exemptions are claimed.

Arduino Boards are fully compliant with the related requirements of European Union Regulation (EC) 1907 /2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). We declare none of the SVHCs (https://echa.europa.eu/web/guest/candidate-list-table), the Candidate List of Substances of Very High Concern for authorization currently released by ECHA, is present in all products (and also package) in quantities totaling in a concentration equal or above 0.1%. To the best of our knowledge, we also declare that our products do not contain any of the substances listed on the "Authorization List" (Annex XIV of the REACH regulations) and Substances of Very High Concern (SVHC) in any significant amounts as specified by the Annex XVII of Candidate list published by ECHA (European Chemical Agency) 1907 /2006/EC.

6.3 Conflict Minerals Declaration

As a global supplier of electronic and electrical components, Arduino is aware of our obligations with regards to laws and regulations regarding Conflict Minerals, specifically the Dodd-Frank Wall Street Reform and Consumer Protection Act, Section 1502. Arduino does not directly source or process conflict minerals such as Tin, Tantalum, Tungsten, or Gold. Conflict minerals are contained in our products in the form of solder, or as a component in metal alloys. As part of our reasonable due diligence Arduino has contacted component suppliers within our supply chain to verify their continued compliance with the regulations. Based on the information received thus far we declare that our products contain Conflict Minerals sourced from conflict-free areas.

7 FCC Caution

Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference

(2) this device must accept any interference received, including interference that may cause undesired operation.

FCC RF Radiation Exposure Statement:

1. This Transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.
2. This equipment complies with RF radiation exposure limits set forth for an uncontrolled environment.
3. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

English: User manuals for license-exempt radio apparatus shall contain the following or equivalent notice in a conspicuous location in the user manual or alternatively on the device or both. This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions:

(1) this device may not cause interference

(2) this device must accept any interference, including interference that may cause undesired operation of the device.

French: Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes :

(1) l' appareil nedoit pas produire de brouillage

(2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

IC SAR Warning:

English This equipment should be installed and operated with minimum distance 20 cm between the radiator and your body.

French: Lors de l' installation et de l' exploitation de ce dispositif, la distance entre le radiateur et le corps est d 'au moins 20 cm.

Important: The operating temperature of the EUT can't exceed 85℃ and shouldn't be lower than -40℃.

Hereby, Arduino S.r.l. declares that this product is in compliance with essential requirements and other relevant provisions of Directive 2014/53/EU. This product is allowed to be used in all EU member states.

8 Company Information

Company name	Arduino S.r.l
Company Address	Via Andrea Appiani 25 20900 MONZA Italy

9 Reference Documentation

Reference	Link
Arduino IDE (Desktop)	https://www.arduino.cc/en/Main/Software
Arduino IDE (Cloud)	https://create.arduino.cc/editor
Cloud IDE Getting Started	https://create.arduino.cc/projecthub/Arduino_Genuino/getting-started-with-arduino-web-editor-4b3e4a
Arduino Pro Website	https://www.arduino.cc/pro
Project Hub	https://create.arduino.cc/projecthub?by=part&part_id=11332&sort=trending
Library Reference	https://www.arduino.cc/reference/en/
Online Store	https://store.arduino.cc/

10 Revision History

Date	Revision	Changes
xx/06/2021	1	Datasheet release

PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

Key Features

- 3W Output at 10% THD with a 4Ω Load and 5V Power Supply
- Filterless, Low Quiescent Current and Low EMI
- Low THD+N
- Superior Low Noise
- Efficiency up to 90%
- Short Circuit Protection
- Thermal Shutdown
- Few External Components to Save the Space and Cost
- Pb-Free Package

Applications

- LCD Monitors / TV Projectors
- Notebook Computers
- Portable Speakers
- Portable DVD Players, Game Machines
- Cellular Phones/Speaker Phones

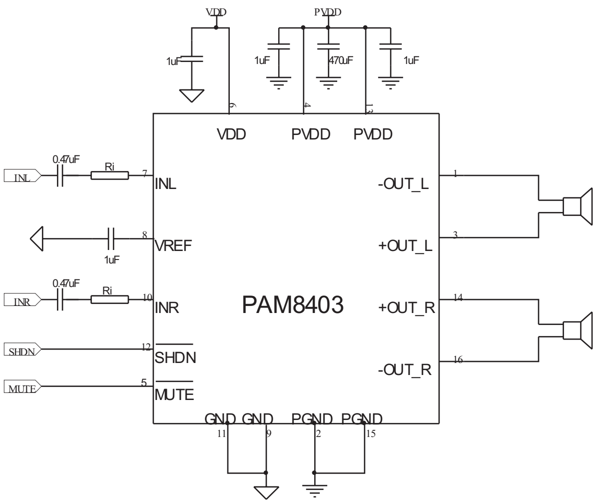
General Description

The PAM8403 is a 3W, class-D audio amplifier. It offers low THD+N, allowing it to produce high-quality sound reproduction. The new filterless architecture allows the device to drive the speaker directly, without needing low-pass output filters, which will save the system cost and PCB area.

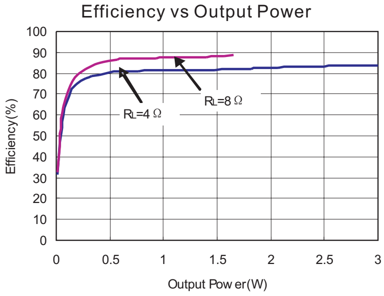
With the same numbers of external components, the efficiency of the PAM8403 is much better than class-AB cousins. It can extend the battery life, ideal for portable applications.

The PAM8403 is available in a DIP-16 and SOP-16 packages.

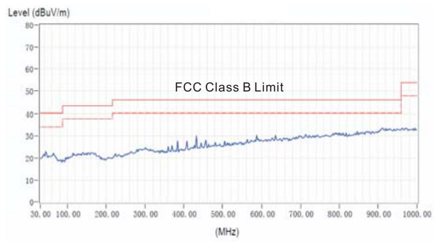
Typical Application



Efficiency vs Output Power



Radiated Emissions



Power Analog Microelectronics, Inc

English:www.poweranalog.com 中文：www.power-analog.com 03/2007

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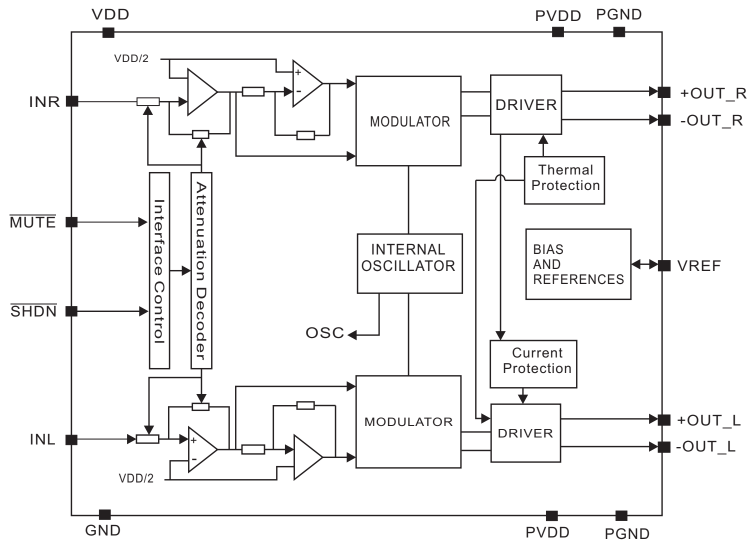
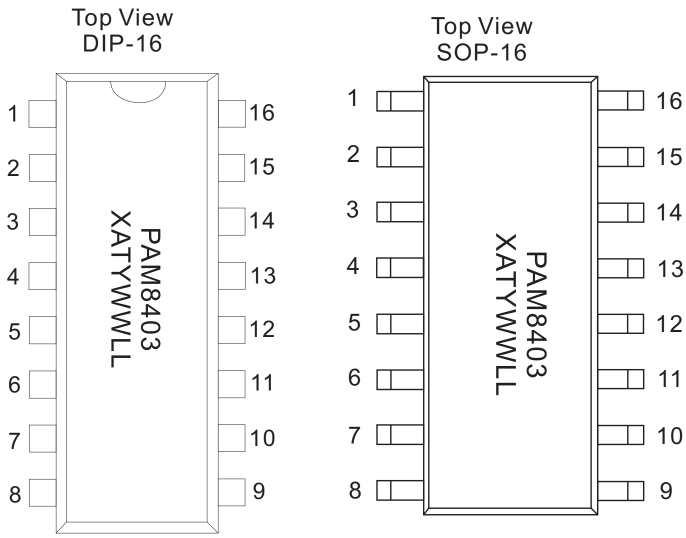
PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

Block Diagram



Pin Configuration & Marking Information



X: Internal Code
A: Assembly Code
T: Testing Code
Y: Year
WW: Weekly
LL: Internal Code

Power Analog Microelectronics, Inc

English:www.poweranalog.com 中文：www.power-analog.com 03/2007

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PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

Pin Descriptions

Pin Number	Pin Name	Description
1	-OUT_L	Left Channel Negative Output
2	PGND	Power GND
3	+OUT_L	Left Channel Positive Output
4	PVDD	Power VDD
5	$\overline{\text{MUTE}}$	Mute Control Input（active low）
6	VDD	Analog VDD
7	INL	Left Channel Input
8	VREF	Internal analog reference, connect a bypass capacitor from VREF to GND
9	GND	Analog GND
10	INR	Right Channel Input
11	GND	Analog GND
12	$\overline{\text{SHDN}}$	Shutdown Control Input(active low)
13	PVDD	Power VDD
14	+OUT_R	Right Channel Positive Output
15	PGND	Power GND
16	-OUT_R	Right Channel Negative Output

Absolute Maximum Ratings

These are stress ratings only and functional operation is not implied. Exposure to absolute maximum ratings for prolonged time periods may affect device reliability. All voltages are with respect to ground.

Supply Voltage...5.5V
Operation Temperature Range...........-40℃ to 85℃
Maximum Junction Temperature..................150℃

Operation Junction Temperature......-40℃ to 125℃
Storage Temperature......................-65℃ to 150℃
Soldering Temperature........................300℃,5sec

Recommended Operating Conditions

Supply voltage Range..........................2.5V to 5V
Operation Temperature Range...........-40℃to 85℃

Junction Temperature Range...........-40℃ to 125℃

Thermal Information

Parameter	Symbol	Package	Maximum	Unit
Thermal Resistance (Junction to Ambient)	θ_{JA}	DIP-16	90	℃/W
		SOP-16	110	

PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

Electrical Characteristic

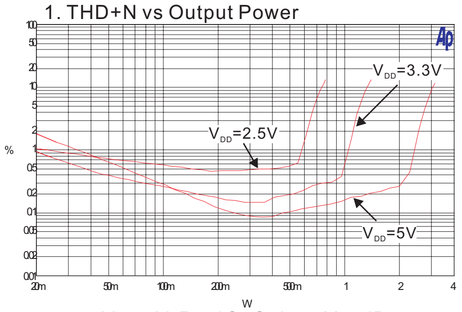
V_{DD}=5V, Gain = 18.5dB, R_L=8Ω(Note 1),T_A=25℃， unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage Range	V_{DD}		2.5		5	V
Quiescent Current	I_Q	No Load		10	15	mA
		R_L=8Ω		11		
		R_L=4Ω		12		
Mute Current	I_{MUTE}	V_{MUTE}=0V		1.5	3	mA
Shutdown Current	I_{SHDN}	V_{SHDN}=0V		45	100	uA
$\overline{SHDN}$ Input High	V_{SH}		1.2			V
$\overline{SHDN}$ Input Low	V_{SL}	Note 2			0.5	
$\overline{MUTE}$ Input High	V_{MH}		1.2			V
$\overline{MUTE}$ Input Low	V_{ML}	Note 3			0.5	
Output Offset Voltage	V_{OS}	No Load		10	30	mV
Drain-Source On-State Resistance	$R_{DS(ON)}$	I_{DS}=0.5A, P MOSFET		0.3	0.40	Ω
		I_{DS}=0.5A, N MOSFET		0.22	0.35	
Output Power	P_O	THD+N=10%, 1kHz, R_L= 8Ω	1.55	1.7		W
		THD+N=10%, 1kHz, R_L= 4Ω	2.85	3.0		
Total Harmonic Distortion Plus Noise	THD+N	R_L = 8Ω，P_O=0.25W		0.08		%
		R_L = 8Ω，P_O=1.1W		0.27	1.0	
		R_L = 4Ω，P_O=0.35W		0.08		
		R_L= 4Ω，P_O=2.0W		0.3	1.0	
Power Supply Ripple Rejection	PSRR	No input, f=1KHz, Vpp=200mV	45	55		dB
Channel Separation	CS	P_O=1W, R_L=4Ω	60	80		dB
Oscillator Frequency	f_{OSC}	P_O=1W, R_L=8Ω	250	350	450	kHz
Efficiency	η	P_O=1.7W,f=1kHz, R_L=8Ω	85	89		%
		P_O=3.0W,f=1kHz, R_L=4Ω	80	83		%
Signal Noise Ratio	SNR	f =20 to 20KHz, R_L=4Ω	65	80		dB
		f =20 to 20KHz, R_L=8Ω	65	80		dB
Over Temperature Protection	OTP			120		℃
Over Temperature Hysteresis	OTH			40		℃

Note 1: All the loads here are delicate to use for speaker.
Note 2: Grounded or <0.9V to Shutdown
Note 3: Grounded or <0.9V to Mute

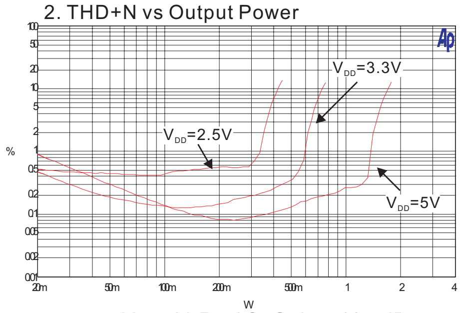
Typical Operating Characteristics (T_A=25°C)

1. THD+N vs Output Power



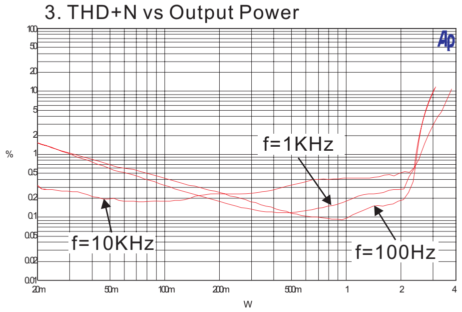
V_{DD}=5V, R_L=4Ω, Gain = 18.5dB

2. THD+N vs Output Power



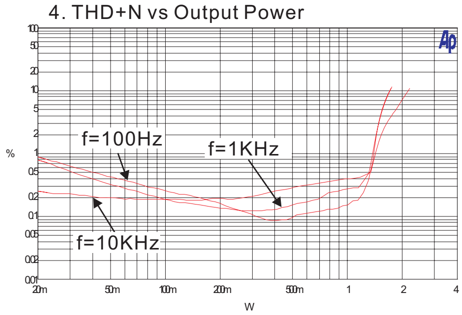
V_{DD}=5V, R_L=8Ω, Gain = 18.5dB

3. THD+N vs Output Power



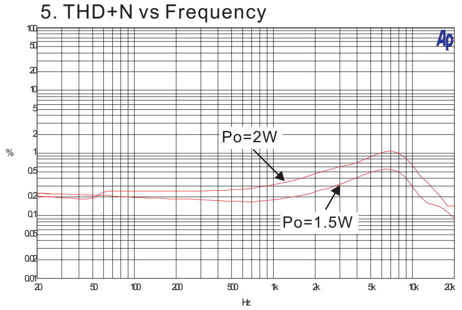
V_{DD}=5V, R_L=4Ω, P_O=0.8W,Gain = 18.5dB

4. THD+N vs Output Power



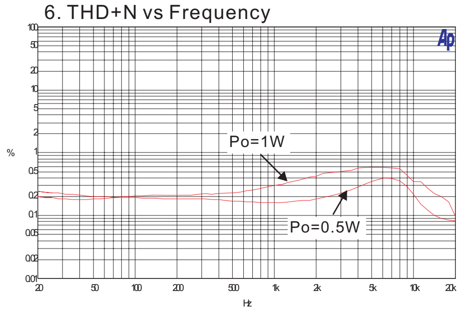
V_{DD}=5V, R_L=8Ω, P_O=1.5W,Gain = 18.5dB

5. THD+N vs Frequency



V_{DD}=5V, R_L=4Ω,Gain = 18.5dB

6. THD+N vs Frequency



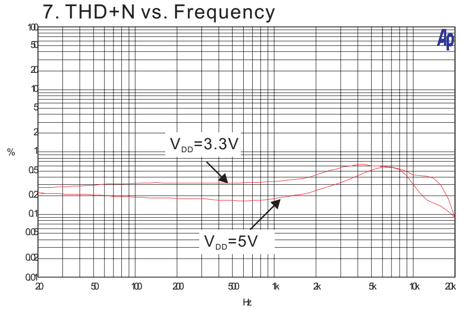
V_{DD}=5V, R_L=8Ω,Gain = 18.5dB

PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

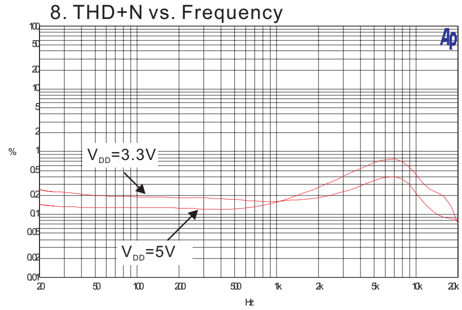
Typical Operating Characteristics (continued)

7. THD+N vs. Frequency



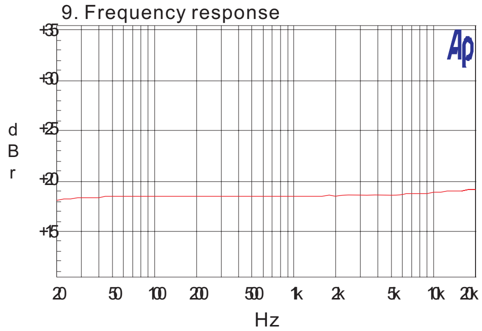
Po=0.8W,R_L=4Ω,Gain=18.5dB

8. THD+N vs. Frequency



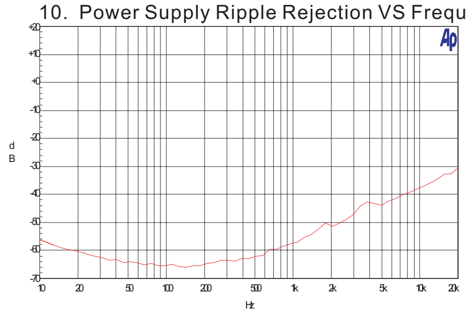
Po=0.1W,R_L=8Ω,Gain=18.5dB

9. Frequency response



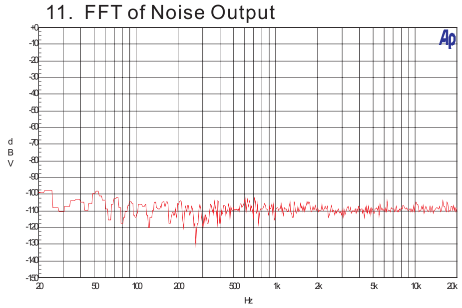
V_{DD}=5V, Gain =18.5dB

10. Power Supply Ripple Rejection VS Frequency



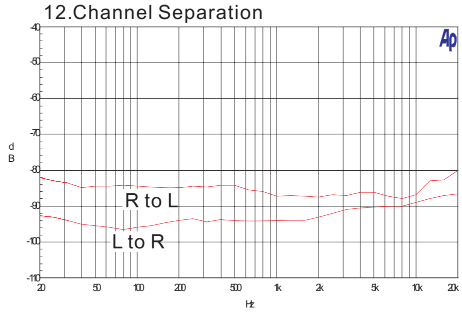
V_{DD}=5V with 200mVpp Ripple

11. FFT of Noise Output



V_{DD}=5V, Gain = 18.5dB

12.Channel Separation



V_{DD}=5V, R_L=4Ω, P_O=1.0W,Gain = 18.5dB

PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

Application Notice

1. When the PAM8403 works with LC filters, it should be connected with the speaker before it's powered on, otherwise it will be damaged easily.

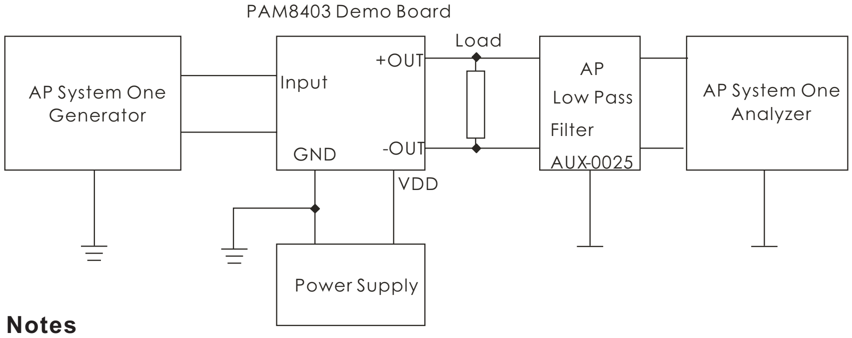
2. When the PAM8403 works without LC filters, it's better to add a ferrite chip bead at the outgoing line of speaker for suppressing the possible electromagnetic interference.

3. The absolute maximum rating of the PAM8403 operation voltage is 5.5V. When the PAM8403 is powered with 4 battery cells, it's worth noting that the voltage of 4 new dry or alkaline batteries is over 6V, higher than its maximum operation voltage, which will probably make the device damaged. Therefore, it's recommended to use either 4 Ni-MH (Nickel Metal Hydride) rechargeable batteries or 3 dry or alkaline batteries.

4. It should not make the input signal too high, which will cause the clipping of output signal when increasing the volume. Because the digital volume control of the PAM8403 has big gain, it will make the device damaged.

5. When testing the PAM8403 without LC filters by using resistor instead of speaker as the output load, the test results, e.g. THD or efficiency, will be worse than those of using speaker as load.

Test Setup for Performance Testing



Notes

1. The AP AUX-0025 low pass filter is necessary for every class-D amplifier measurement done by AP analyzer.

2. Two 22uH inductors are used in series with load resistor to emulate the small speaker for efficiency measurement.

Application Information

Maximum Gain

As shown in block diagram(page 2),the PAM8403 has two internal amplifiers stage. The first stage's gain is externally configurable, while the second stage's is internally fixed in a fixed-gain, inverting configuration. The closed-loop gain of the first stage is set by selecting the ratio of R_f to R_i while the second stage's gain is fixed at 1.4x.The output of amplifier one serves as the input to amplifier two which results in both amplifiers producing signals identical in magnitude, but out of phase by 180°. Consequently, the differential gain for the IC is

A_{VD}=20*log [2*(R_f/R_i)*1.4]

The PAM8403 sets maximum R_f=85KΩ, minimum R_i=15KΩ, so the maximum closed-gain is 24dB.

Mute Operation

The $\overline{\text{MUTE}}$ pin is an input for controlling the output state of the PAM8403. A logic low on this pin disables the outputs, and a logic high on this pin enables the outputs. This pin may be used as a quick disable or enable of the outputs without a volume fade. Quiescent current is listed in the electrical characteristic table. The $\overline{\text{MUTE}}$ pin can be left floating due to the pull-up internal.

Shutdown operation

In order to reduce power consumption while not in use, the PAM8403 contains shutdown circuitry that is used to turn off the amplifier's bias circuitry. This shutdown feature turns the amplifier off when logic low is placed on the $\overline{\text{SHDN}}$ pin. By switching the $\overline{\text{SHDN}}$ pin connected to GND, the PAM8403 supply current draw will be minimized in idle mode. The $\overline{\text{SHDN}}$ pin can be left floating due to the pull-up internal.

Power supply decoupling

The PAM8403 is a high performance CMOS audio amplifier that requires adequate power supply decoupling to ensure the output THD and PSRR are as low as possible. Power supply decoupling is affecting low frequency response. Optimum decoupling is achieved by using two capacitors of different types that target different types of noise on the power supply leads. For higher frequency transients, spikes, or digital hash on the line, a good low equivalent-series-resistance (ESR) ceramic capacitor, typically 1.0μF, placed as close as possible to the device V_{DD} terminal works best. For filtering lower-frequency noise signals, a larger capacitor of 20μF(ceramic) or greater placed near the audio power amplifier is recommended.

Input Capacitor (C_i)

Large input capacitors are both expensive and space hungry for portable designs. Clearly, a certain sized capacitor is needed to couple in low frequencies without severe attenuation. But in many cases the speakers used in portable systems, whether internal or external, have little ability to reproduce signals below 100Hz to 150Hz. Thus, using a large input capacitor may not increase actual system performance. In this case, input capacitor (C_i) and input resistance (R_i) of the amplifier form a high-pass filter with the corner frequency determined equation below,

$$f_C = \frac{1}{2\pi R_i C_i}$$

In addition to system cost and size, click and pop performance is affected by the size of the input coupling capacitor, C_i. A larger input coupling capacitor requires more charge to reach its quiescent DC voltage (nominally 1/2 V_{DD}). This charge comes from the internal circuit via the feedback and is apt to create pops upon device enable. Thus, by minimizing the capacitor size based on necessary low frequency response, turn-on pops can be minimized.

Analog Reference Bypass Capacitor (C_{BYP})

The Analog Reference Bypass Capacitor (C_{BYP}) is the most critical capacitor and serves several important functions. During start-up or recovery from shutdown mode, C_{BYP} determines the rate at which the amplifier starts up. The second function is to reduce noise produced by the power supply caused by coupling into the output drive signal. This noise is from the internal analog reference to the amplifier, which appears as degraded PSRR and THD+N.

Bypass capacitor (C_{BYP}) values of 0.47μF to 1.0μF ceramic is recommended for the best THD and noise performance. Increasing the bypass capacitor reduces clicking and popping noise

PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

Application Information(continued)

from power on/off and entering and leaving shutdown.

Power On/Off Pop noise Reducing

Power on pop noise reducing: The PAM8403 contains circuitry to minimize turn-on pop noise. In this case, turn-on refers to either power supply turn-on or device coming out shutdown mode. When the device is turning on, the amplifiers are internally muted. An internal current source ramps up the voltage of VREF pin. The device will remain in mute mode until the VREF pin has reached its half supply voltage, 1/2 V_{DD}. As soon as the VREF node is stable, the device will become fully operational.

Power off pop noise reducing: for the best power-off pop performance, the amplifier should be placed in the mute /shutdown mode prior to removing the power supply voltage. An external circuit shows in figure 2 also can minimize the power off pop noise: the V_{TH} is set around 1.3V@V_{DD}=5V which is a little higher than the mute/shutdown threshold voltage, R1 reduce the internal resistor temperature coefficient and capacitor C speeds up the response. Note that this circuit can only work in between V_{DD}= 4.5V to 5.5V, otherwise the PAM8403 can not work, other than the ratio of the resistor divider needs to be changed.

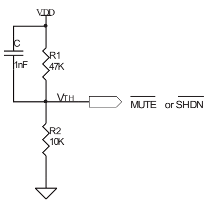


Figure 2: External Circuit to reduce power off pop noise

Under Voltage Lock-out (UVLO)

The PAM8403 incorporates circuitry designed to detect when the supply voltage is low. When the supply voltage drops to 2.0V or below, the PAM8403 outputs are disable, and the device comes out of this state and starts to normal functional until $V_{DD} \geqslant 2.2$V.

Short Circuit Protection (SCP)

The PAM8403 has short circuit protection circuitry on the outputs that prevents damage to the device during output-to-output and output-to-GND short. When a short circuit is detected on the outputs, the outputs are disable immediately. If the short was removed, the device activates again.

Over Temperature Protection

Thermal protection on the PAM8403 prevents damage to the device when the internal die temperature exceeds 120℃. There is a 15 degree tolerance on this trip point from device to device. Once the die temperature exceeds the thermal set point, the device outputs are disabled. This is not a latched fault. The thermal fault is cleared once the temperature of the die is reduced by 40℃ . This large hysteresis will prevent motor boating sound well and the device begins normal operation at this point with no external system interaction.

How to Reduce EMI (Electro Magnetic Interference)

A simple solution is to put an additional capacitor 1000uF at power supply terminal for power line coupling if the traces from amplifier to speakers are short (<20CM).

Most applications require a ferrite bead filter which shows at Figure 3. The ferrite filter reduces EMI around 1 MHz and higher. When selecting a ferrite bead, choose one with high impedance at high frequencies, but low impedance at low frequencies.

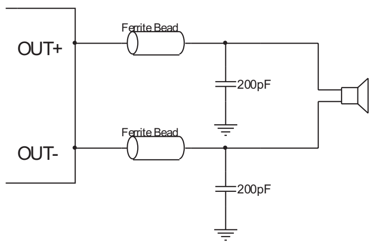


Figure 3: Ferrite Bead Filter to reduce EMI

PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

Ordering Information

PAM8403 X X

Shipping

Package Type

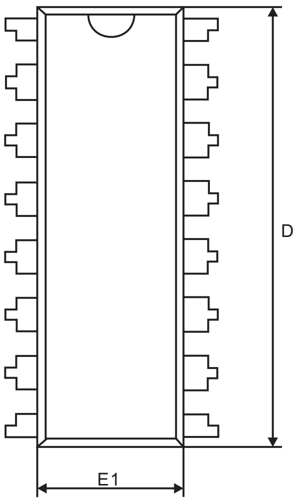
Part Number	Marking	Package Type	Standard Package
PAM8403QT	PAM8403 XATYWWLL	DIP-16	30 Units/Tube
PAM8403DT	PAM8403 XATYWWLL	SOP-16	50 Units/Tube
PAM8403DR	PAM8403 XATYWWLL	SOP-16	2,500 Units/Tape&Reel

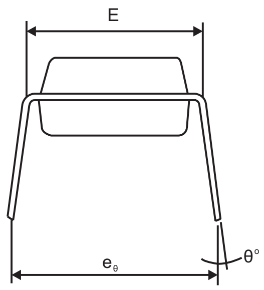
Please consult PAM sales office or authorized Rep. /Distributor for detailed ordering information.

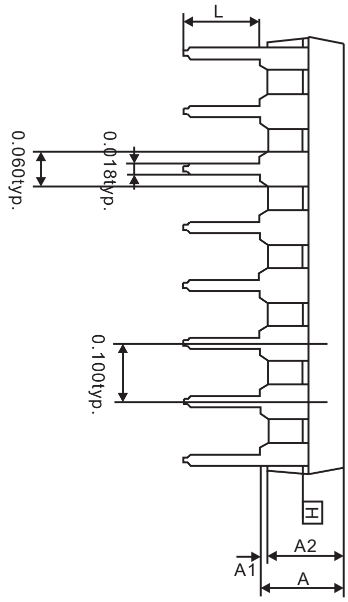
PAM8403
Filterless 3W Class-D Stereo Audio Amplifier

Outline Dimension

DIP-16







Symbols	MIN	TYP	MAX
A	-	-	0.210
A1	0.015	-	-
A2	0.125	-	-
D	0.735	0.755	0.775
E	0.300 BSC.		
E1	0.245	0.250	0.255
L	0.115	0.130	0.150
e_θ	0.335	0.355	0.375
θ°	0	7	15

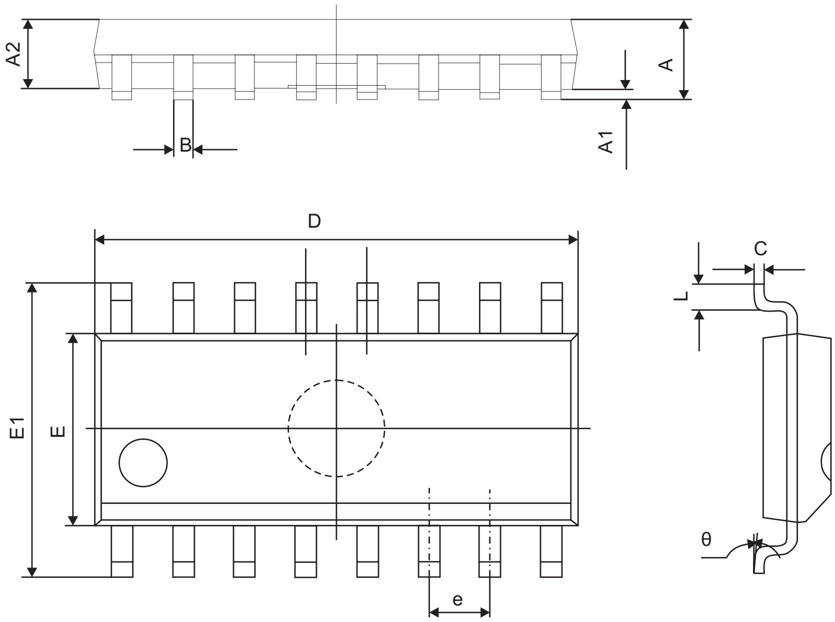
Unit: Inch

PAM8403

Filterless 3W Class-D Stereo Audio Amplifier

Outline Dimension

SOP-16



Symbol	Dimensions Millimeters	
	Min	Max
A	1.350	1.750
A1	0.100	0.250
A2	1.350	1.550
B	0.330	0.510
C	0.190	0.250
D	9.800	10.000
E	3.800	4.000
E1	5.800	6.300
e	1.270(TYP)	
L	0.400	1.270
θ	0º	8º

DFPLayer Mini

1. Summary

1.1 .Brief Instruction

DFPLayer Mini module is a serial MP3 module provides the perfect integrated MP3, WMV hardware decoding. While the software supports TF card driver, supports FAT16, FAT32 file system. Through simple serial commands to specify music playing, as well as how to play music and other functions, without the cumbersome underlying operating, easy to use, stable and reliable are the most important features of this module.

1.2 .Features

- Support Mp3 and WMV decoding
- Support sampling rate of 8KHz,11.025KHz,12KHz,16KHz,22.05KHz,24KHz,32KHz,44.1KHz,48KHz
- 24-bit DAC output, dynamic range support 90dB, SNR supports 85dB
- Supports FAT16, FAT32 file system, maximum support 32GB TF card
- A variety of control modes, serial mode, AD key control mode
- The broadcast language spots feature, you can pause the background music being played
- Built-in 3W amplifier
- The audio data is sorted by folder; supports up to 100 folders, each folder can be assigned to 1000 songs
- 30 levels volume adjustable, 10 levels EQ adjustable.

1.3 .Application

- Car navigation voice broadcast
- Road transport inspectors, toll stations voice prompts
- Railway station, bus safety inspection voice prompts
- Electricity, communications, financial business hall voice prompts
- Vehicle into and out of the channel verify that the voice prompts
- The public security border control channel voice prompts
- Multi-channel voice alarm or equipment operating guide voice
- The electric tourist car safe driving voice notices
- Electromechanical equipment failure alarm
- Fire alarm voice prompts
- The automatic broadcast equipment, regular broadcast.

2. Module Application Instruction

2.1. Specification Description

Item	Description
MP3Format	1、Support 11172-3 and ISO13813-3 layer3 audio decoding
	2、Support sampling rate (KHZ):8/11.025/12/16/22.05/24/32/44.1/48
	3、Support Normal、Jazz、Classic、Pop、Rock etc
UART Port	Standard Serial; TTL Level; Baud rate adjustable(default baud rate is 9600)
Working Voltage	DC3.2~5.0V; Type :DC4.2V
Standby Current	20mA
Operating Temperature	-40~+70
Humidity	5% ~95%

Table 2.1 Specification Description

DFPLayer Mini

2.2 .Pin Description

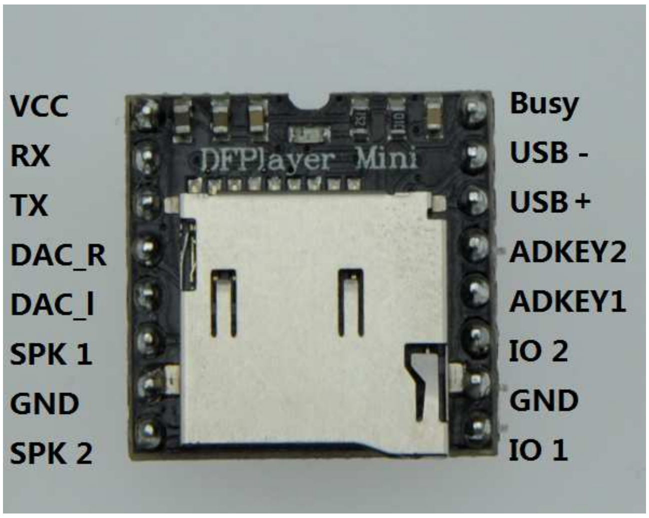


Figure 2.1

No	Pin	Description	Note
1	VCC	Input Voltage	DC3.2~5.0V;Type: DC4.2V
2	RX	UART serial input	
3	TX	UART serial output	
4	DAC_R	Audio output right channel	Drive earphone and amplifier
5	DAC_L	Audio output left channel	Drive earphone and amplifier
6	SPK2	Speaker-	Drive speaker less than 3W
7	GND	Ground	Power GND
8	SPK1	Speaker+	Drive speaker less than 3W
9	IO1	Trigger port 1	Short press to play previous（long press to decrease volume）
10	GND	Ground	Power GND
11	IO2	Trigger port 2	Short press to play next（long press to increase volume）
12	ADKEY1	AD Port 1	Trigger play first segment
13	ADKEY2	AD Port 2	Trigger play fifth segment
14	USB+	USB+ DP	USB Port
15	USB-	USB- DM	USB Port
16	BUSY	Playing Status	Low means playing \High means no

Table 2.2 Pin Description

DFPLayer Mini

3. Serial Communication Protocol

Serial port as a common communication in the industrial control field, we conducted an industrial level of optimization, adding frame checksum, retransmission, error handling, and other measures to significantly strengthen the stability and reliability of communication, and can expansion more powerful RS485 for networking functions on this basis, serial communication baud rate can set as your own, the default baud rate is 9600

3.1. Serial Communication Format

Support for asynchronous serial communication mode via PC serial sending commands
Communication Standard:9600 bps
Data bits :1
Checkout :none
Flow Control :none

Format: $S VER Len CMD Feedback para1 para2 checksum $O		
$S	Start byte 0x7E	Each command feedback begin with $, that is 0x7E
VER	Version	Version Information
Len	the number of bytes after “Len”	Checksums are not counted
CMD	Commands	Indicate the specific operations, such as play / pause, etc.
Feedback	Command feedback	If need for feedback, 1: feedback, 0: no feedback
para1	Parameter 1	Query high data byte
para2	Parameter 2	Query low data byte
checksum	Checksum	Accumulation and verification [not include start bit $]
$O	End bit	End bit 0xEF

For example, if we specify play NORFLASH, you need to send: 7E FF 06 09 00 00 04 FF DD EF
Data length is 6, which are 6 bytes [FF 06 09 00 00 04]. Not counting the start, end, and verification.

3.2 .Serial Communication Commands

1).Directly send commands, no parameters returned

CMD	Function Description	Parameters(16 bit)
0x01	Next	
0x02	Previous	
0x03	Specify tracking(NUM)	0-2999
0x04	Increase volume	
0x05	Decrease volume	
0x06	Specify volume	0-30
0x07	Specify EQ(0/1/2/3/4/5)	Normal/Pop/Rock/Jazz/Classic/Base
0x08	Specify playback mode (0/1/2/3)	Repeat/folder repeat/single repeat/ random

DFPLayer Mini

0x09	Specify playback source(0/1/2/3/4)	U/TF/AUX/SLEEP/FLASH
0x0A	Enter into standby – low power loss	
0x0B	Normal working	
0x0C	Reset module	
0x0D	Playback	
0x0E	Pause	
0x0F	Specify folder to playback	1~10(need to set by user)
0x10	Volume adjust set	{DH＝1:Open volume adjust }{DL: set volume gain 0~31}
0x11	Repeat play	{1:start repeat play}{0:stop play}

2).Query the System Parameters

Commands	Function Description	Parameters(16 bit)
0x3C	STAY	
0x3D	STAY	
0x3E	STAY	
0x3F	Send initialization parameters	0 - 0x0F(each bit represent one device of the low-four bits)
0x40	Returns an error, request retransmission	
0x41	Reply	
0x42	Query the current status	
0x43	Query the current volume	
0x44	Query the current EQ	
0x45	Query the current playback mode	
0x46	Query the current software version	
0x47	Query the total number of TF card files	
0x48	Query the total number of U-disk files	
0x49	Query the total number of flash files	
0x4A	Keep on	
0x4B	Queries the current track of TF card	
0x4C	Queries the current track of U-Disk	
0x4D	Queries the current track of Flash	

3.3. Returned Data of Module

3.3.1. Returned Data of Module Power-on

1).The module power on, require a certain of the time initialization, this time is determined by U-disk, TF card, flash, etc. device 's file numbers, general situation in the 1.5 ~ 3Sec. If module initialization data has not been

DFPLayer Mini

sent out within the time, indicating that the module initialization error, please reset the module's power supply, and detect hardware connecting;

2).The module initialization data including online devices, such as sending 7E FF 06 3F 00 00 01 xx xx EF, DL = 0x01 describe only the U-disk online during power-on, Other data are seen as the table below:

U-Disk on-line	7E FF 06 3F 00 00 01 xx xx EF	Each device are or relationship
TF Card on-line	7E FF 06 3F 00 00 02 xx xx EF	
PC on-line	7E FF 06 3F 00 00 04 xx xx EF	
FLASH on-line	7E FF 06 3F 00 00 08 xx xx EF	
U-disk & TF Card on-line	7E FF 06 3F 00 00 03 xx xx EF	

3).MCU will not send corresponding control commands until module initialization sending commands or the module will not process the commands sent by MCU, and will also affect the normal initialization of the module.

3.3.2 .Returned Data of Track Finished Playing

U-Disk finish playback 1st track	7E FF 06 3C 00 00 01 xx xx EF
U-Disk finish playback 2nd track	7E FF 06 3C 00 00 02 xx xx EF
TF card finish playback 1st track	7E FF 06 3D 00 00 01 xx xx EF
TF card finish playback 2nd track	7E FF 06 3D 00 00 02 xx xx EF
Flash finish playback 1st track	7E FF 06 3E 00 00 01 xx xx EF
Flash finish playback 2nd track	7E FF 06 3E 00 00 02 xx xx EF

1.The module will enter into pause status automatically after being specified playing, if customers need such application, they can specify track to play ,the module will enter into pause status after finishing playing ,and wait for the commands sent by MCU.

2 In addition, we opened a dedicated I/O as decoding and pausing status indication. See Pin 16, Busy
1).Output high level at playback status;
2).Output low level at pause status and module sleep;

3. For continuous playback applications, it can be achieved as below, if it finishes the first tracking of the TF card, it will return

7E FF 06 3D 00 00 01 xx xx EF
3D ---- U-disk command
00 01 ---- expressed finished playing tracks.

If the external MCU receives this command, please wait 100ms. And then sending the playback command [7E FF 06 0D 00 00 00 FF EE EF], because inside the module it will first initialize the next track information. In this case, the module can be played continuously.

4. If the currently finish playing the first song, the track pointer automatically point to second song, If you send a "play the next one" command, then the module will playback the third song. And, if the module finishes playing the last one, the player will automatically jump to the first pointer, and pause.

5. After specifying device, the module play pointer will point to device root directory of the first track, and enters the pause state, and wait MCU sending track playing command.

3.3.3 .Returned Data of Module Responds

DFPLayer Mini

FLASH finish play the 1st track	7E FF 06 3E 00 00 01 xx xx EF

1). in order to strengthen the stability of the data communication, we have increased response processing; ACKB byte is set whether need to reply to response. So that to ensure each communication get handshake signals, which will indicate the module has been successfully received data sent by the MCU and process immediately.
2).For general applications, customers can freely choose, without this response processing is also ok.

3.3.4 .Returned Data of Module Error

Module is busy	7E FF 06 40 00 00 00 xx xx EF
A frame data are not all received	7E FF 06 40 00 00 01 xx xx EF
Verification error	7E FF 06 40 00 00 02 xx xx EF

1). In order to strengthen the stability of the data communication, we added data error handling mechanism. Module will responds information after receiving error data format;

2). In the case of relatively harsh environment, it is strongly recommended that customers process this command. If the application environment in general, you no need handle it;

3).The module returns busy, basically when module power-on initialization will return, because the modules need to initialize the file system.

3.3.5. Push-in and Pull-out information of Device

Push in U-disk	7E FF 06 3A 00 00 01 xx xx EF
Push in TF card	7E FF 06 3A 00 00 02 xx xx EF
Pull out U-disk	7E FF 06 3B 00 00 01 xx xx EF
Pull out TF card	7E FF 06 3B 00 00 02 xx xx EF

1).For the flexibility of the module, we particularly add command feedback of push-in and pull-out device. Let user know the working status of the module.

2).When push-in device, we default playback the first track of device root directory as audition, if users do not need this feature, you can wait 100ms after receiving the message of push –in serial device ,and then send pause command.

3.4 Serial Commands

3.4.1. Commands of Specify Track Play

Our instructions are given in support of the specified track is playing, the song selection ranges from 0 to 2999. Actually can support more, because it involves the reasons to the file system, support for the song too much, it will cause the system to operate slowly, and usually the application does not need to support so many files. If the customer has unconventional applications, please communicate with us in advance.

1).For example, select the first song played, serial transmission section: 7E FF 06 03 00 00 01 FF E6 EF
7E --- START command
FF --- Version Information
06 --- Data length (not including parity)
03 --- Representative No.
00 --- If need to acknowledge [0x01: need answering, 0x00: do not need to return the response]
00 --- Tracks high byte [DH]
01 --- Tracks low byte [DL], represented here is the first song played
FF --- Checksum high byte
E6 --- Checksum low byte
EF --- End Command

DFPLayer Mini

2).For selections, if choose the 100th song, first convert 100 to hexadecimal, the default is double-byte, it is 0x0064.
DH = 0x00; DL = 0x64

3).If you choose to play the 1000th, first convert 1000 to hexadecimal, the default is double-byte, it is 0x03E8
DH = 0x03; DL = 0xE8

4).And so on to the other operations, as in the embedded area in hexadecimal is the most convenient method of operating.

3.4.2 .Commands of Specify Volume

1). Our system power-on default volume is 30, if you want to set the volume, then directly send the corresponding commands.
2).For example, specify the volume to 15, serial port to send commands: 7E FF 06 06 00 00 0F FF D5 EF
3).DH = 0x00; DL = 0x0F, 15 is converted to hexadecimal 0x000F, can refer to the instructions of playing track section.

3.4.3 .Specify Device Play

1).The module default support four types of playback devices, the device must be on line, so it can specify playback. The software will automatically detect without user attention.
2).Refer the table as below to select the appropriate command to send
3).Module will automatically enter the Suspend state after the specified device, waiting for the user to specify a track playing. It will take about 200ms from specifying device to the module initialize file information. Please wait for 200ms and then send the specified track command.

Specify playback device –U-disk	7E FF 06 09 00 00 01 xx xx EF	xx xx：Verification
Specify playback device –TF Card	7E FF 06 09 00 00 02 xx xx EF	
Specify playback device -SLEEP	7E FF 06 09 00 00 05 xx xx EF	

3.4.4. Specify File to Play

Specify folder 01 of 001.mp3	7E FF 06 0F 00 01 01 xx xx EF
Specify folder 11 of 100.mp3	7E FF 06 0F 00 0B 64 xx xx EF
Specify folder 99 of 255.mp3	7E FF 06 0F 00 63 FF xx xx EF

1).Specify the folder playback is developed extensions, default folders are named as "01", "11" in this way because our module does not support Chinese characters identify the name of the folder name, in order to stabilize the system switching speeds and songs under each folder default maximum support up to 255 songs, up to 99 folders classification, if customers have special requirements, they need to classify according to the English name, we also can be achieved, but name only is "GUSHI", "ERGE" and other English name.

2).For example, specify "01" folder 100.MP3 file, serial port to send commands : 7E FF 06 0F 00 01 64 xx xx EF
DH: represents the name of the folder, the default support for 99 documents become 01 - 99 named
DL: on behalf of the tracks, the default maximum of 255 songs that 0x01 ~ 0xFF
Please refer to the above set rules for setting tracks

3).to the standard of the module, you must specify both the folder and file name, to lock a file. Individually specified folder or specify the file name alone is also possible, but the document management will be worse.

4).The following diagram illustrates both the folders and file names are specified.

DFPLayer Mini

Figure 3.1folder name

Figure 3.2 file name

3.5. Key Ports

We use the AD module keys, instead of the traditional method of matrix keyboard connection, it is to take advantage of increasingly powerful MCU AD functionality, Our module default configuration 2 AD port, 20 key resistance distribution, if used in strong electromagnetic interference or strong inductive, capacitive load of the occasion, please refer to our "Notes."

1).Refer diagram

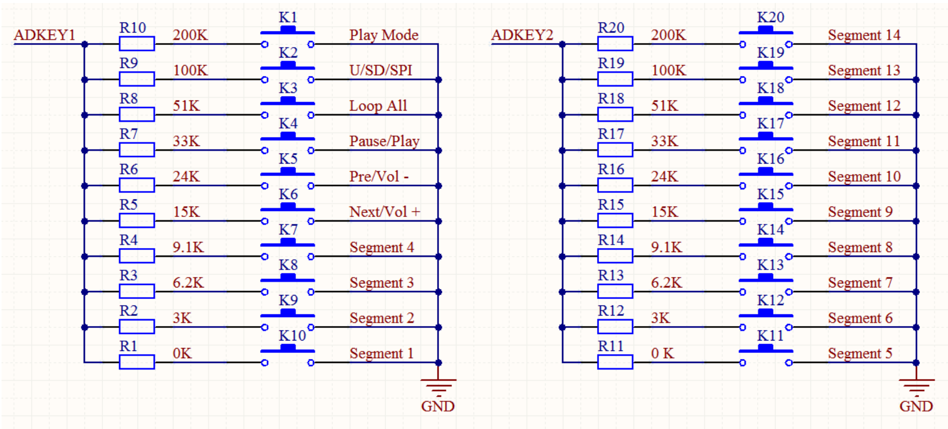


Figure 3.3 ad key refer

2)、20 function keys allocation table

Key	Short Push	Long Push	Description
K1	Play Mode		Switch to interrupt / non interrupted
K2	Playback device switches		U/TF/SPI/Sleep
K3	Operating Mode		All cycle
K4	Play/Pause		
K5	Previous	Vol+	
K6	Next	Vol-	
K7	4	Repeat play tracking 4	Long push always to repeat play
K8	3	Repeat play tracking 3	Long push always to repeat play

DFPLayer Mini

K9	2	Repeat play tracking 2	Long push always to repeat play
K10	1	Repeat play tracking 1	Long push always to repeat play
K11	5	Repeat play tracking 5	Long push always to repeat play
K12	6	Repeat play tracking 6	Long push always to repeat play
K13	7	Repeat play tracking 7	Long push always to repeat play
K14	8	Repeat play tracking 8	Long push always to repeat play
K15	9	Repeat play tracking 9	Long push always to repeat play
K16	10	Repeat play tracking 10	Long push always to repeat play
K17	11	Repeat play tracking 11	Long push always to repeat play
K18	12	Repeat play tracking 12	Long push always to repeat play
K19	13	Repeat play tracking 13	Long push always to repeat play
K20	14	Repeat play tracking 14	Long push always to repeat play

4、Application Circuit

4.1 Serial Communication Connect

Module's serial port is 3.3V TTL level, so the default interface level is 3.3V. If the MCU system is 5V. It is recommended connect a 1K resistor in series.

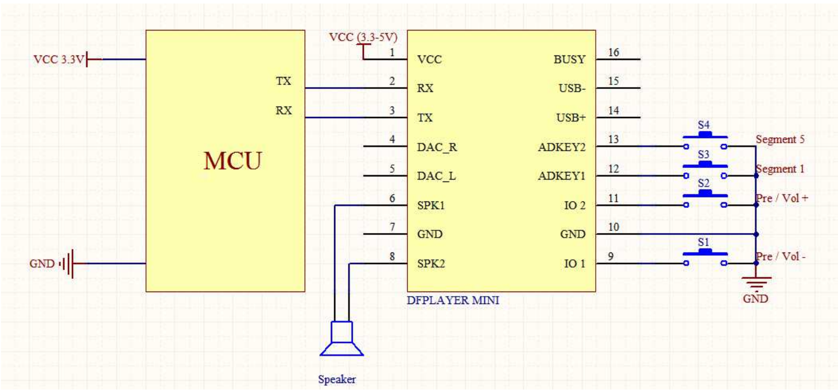


Figure 4.1 Serial Connect (3.3V)

DFPLayer Mini

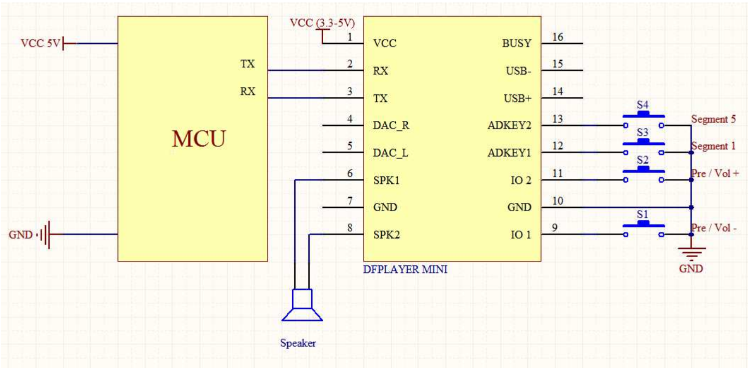


Figure 4.2 Serial Connect (5v)

4.2. Other Refer Diagram

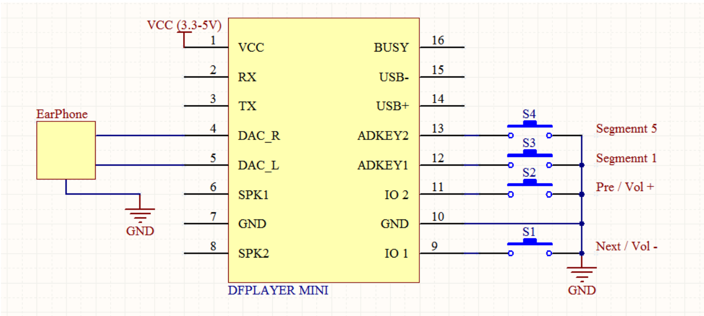


Figure 4.3 headset connect module

Between the headset and the module can string a 100R resistor, make a limiting

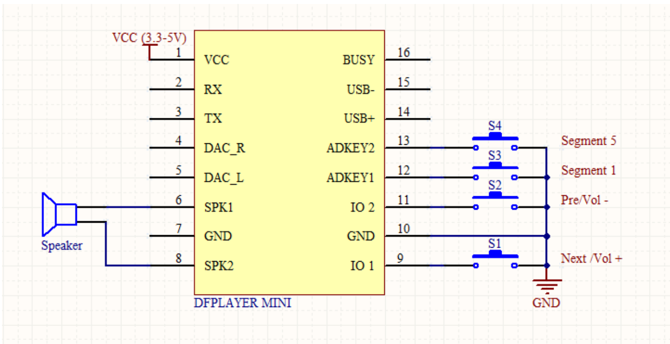


Figure 4.4 speaker connect module

DFPLayer Mini

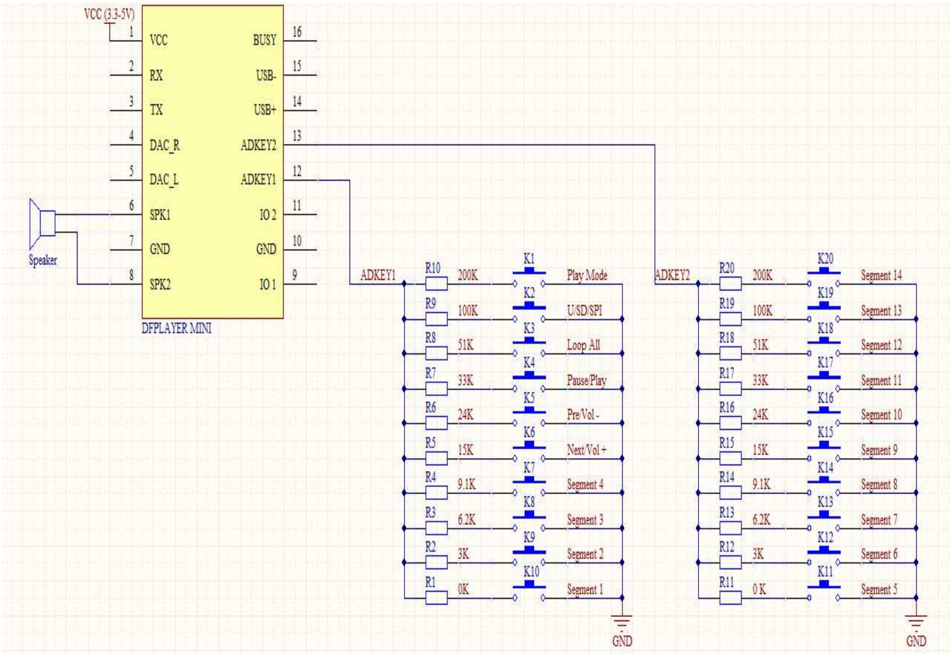


Figure 4.5 Ad key connect refer

5、MP3-TF-16P Size (unit: mm)

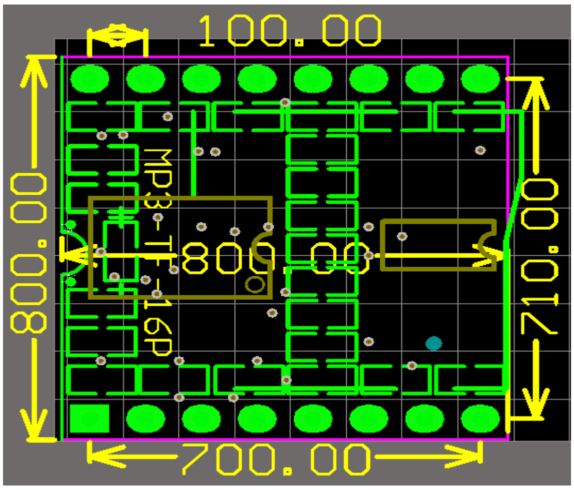


Figure 5.1 pcb size

DFPLayer Mini

6、Note*

I/O Input Specification						
Item	Description	Min	Type	Max	Unit	Test Condition
VIL	Low-Level Input Voltage	-0.3	-	0.3*VDD	V	VDD=3.3V
VIH	High-Level Input Voltage	0.7VDD	-	VDD+0.3	V	VDD=3.3V
I/O Output Specification						
Item	Description	Min	Type	Max	Unit	Test Condition
VOL	Low-Level Output Voltage	-	-	0.33	V	VDD=3.3V
VOH	High-Level Output Voltage	2.7	-	-	V	VDD=3.3V

1. The module's external interfaces are 3.3V TTL level, so please note the level conversion during the hardware circuit design, also in strong interference environment, electromagnetic compatibility note some protective measures, GPIO using opt coupler isolation, increasing TVS etc.

2, ADKEY key values are in accordance with the general use of the environment, if the strong inductive or capacitive load environment, please note that the module power supply is recommended to use a separate isolated power supply, another matched beads and inductors for power filtering, we must ensure that the input power as much as possible the stability and clean. If you really can not be guaranteed, please contact us to reduce the number of keys to redefine wider voltage distribution.

3. For general Serial communication, please pay attention to level conversion. If strong interference environment, or long distance RS485 applications, then please note that signal isolation, in strict accordance with industry standard design communication circuits.

DATASHEET

Raspberry Pi Compute Module 3+

Raspberry Pi Compute Module 3+ Lite

Release 1, January 2019

Table 1: Release History

Release	Date	Description
1	28/01/2019	First release

The latest release of this document can be found at `https://www.raspberrypi.org`

Contents

List of Figures

List of Tables

1 Introduction

The Raspberry Pi Compute Module 3+ (CM3+) is a range of DDR2-SODIMM-mechanically-compatible System on Modules (SoMs) containing processor, memory, eMMC Flash (on non-Lite variants) and supporting power circuitry. These modules allow a designer to leverage the Raspberry Pi hardware and software stack in their own custom systems and form factors. In addition these modules have extra IO interfaces over and above what is available on the Raspberry Pi model A/B boards, opening up more options for the designer.

The CM3+ contains a BCM2837B0 processor (as used on the Raspberry Pi 3B+), 1Gbyte LPDDR2 RAM and eMMC Flash. The CM3+ is currently available in 4 variants, CM3+/8GB, CM3+/16GB, CM3+/32GB and CM3+ Lite, which have 8, 16 and 32 Gigabytes of eMMC Flash, or no eMMC Flash, respectively.

The CM3+ Lite product is the same as CM3+ except the eMMC Flash is not fitted, and the SD/eMMC interface pins are available for the user to connect their own SD/eMMC device.

Note that the CM3+ is electrically identical and, with the exception of higher CPU z-height, physically identical to the legacy CM3 products.

CM3+ modules require a software/firmware image dated November 2018 or newer to function correctly.

2 Features

2.1 Hardware

- Low cost
- Low power
- High availability
- High reliability
  - Tested over millions of Raspberry Pis Produced to date
  - Module IO pins have 15 micro-inch hard gold plating over 2.5 micron Nickel

2.2 Peripherals

- 48x GPIO
- 2x I2C
- 2x SPI
- 2x UART
- 2x SD/SDIO
- 1x HDMI 1.3a
- 1x USB2 HOST/OTG
- 1x DPI (Parallel RGB Display)
- 1x NAND interface (SMI)
- 1x 4-lane CSI Camera Interface (up to 1Gbps per lane)
- 1x 2-lane CSI Camera Interface (up to 1Gbps per lane)
- 1x 4-lane DSI Display Interface (up to 1Gbps per lane)
- 1x 2-lane DSI Display Interface (up to 1Gbps per lane)

2.3 Software

- ARMv8 Instruction Set
- Mature and stable Linux software stack
  - Latest Linux Kernel support
  - Many drivers upstreamed
  - Stable and well supported userland
  - Full availability of GPU functions using standard APIs

3 Block Diagram

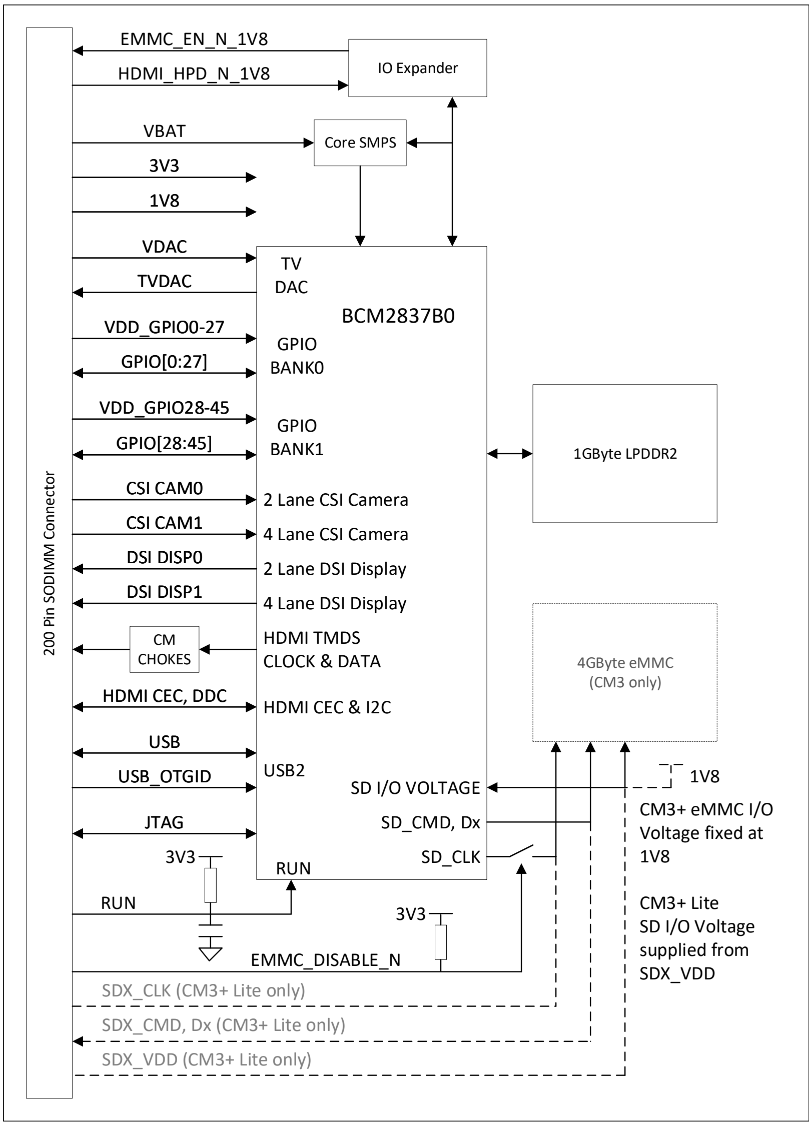


Figure 1: CM3+ Block Diagram

4 Mechanical Specification

The CM3+ modules conform to JEDEC MO-224 mechanical specification for 200 pin DDR2 (1.8V) SODIMM modules and therefore should work with the many DDR2 SODIMM sockets available on the market. **(Please note that the pinout of the Compute Module is not the same as a DDR2 SODIMM module; they are not electrically compatible.)**

The SODIMM form factor was chosen as a way to provide the 200 pin connections using a standard, readily available and low cost connector compatible with low cost PCB manufacture.

The maximum component height on the underside of the Compute Module is 1.2mm.

The maximum component height on the top side of the Compute Module is 2.5mm.

The Compute Module PCB thickness is 1.0mm +/- 0.1mm.

Note that the location and arrangement of components on the Compute Module may change slightly over time due to revisions for cost and manufacturing considerations; however, maximum component heights and PCB thickness will be kept as specified.

Figure 2 gives the CM3+ mechanical dimensions.

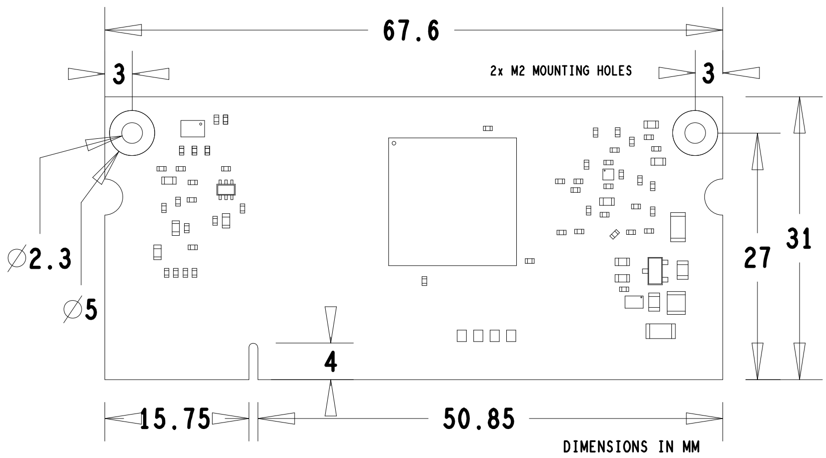


Figure 2: CM3+ Mechanical Dimensions

5 Pin Assignments

CM3+	CM3+ Lite	PIN		PIN	CM3+	CM3+ Lite
GND		1		2	EMMC_DISABLE_N	
GPIO0		3		4	NC	SDX_VDD
GPIO1		5		6	NC	SDX_VDD
GND		7		8	GND	
GPIO2		9		10	NC	SDX_CLK
GPIO3		11		12	NC	SDX_CMD
GND		13		14	GND	
GPIO4		15		16	NC	SDX_D0
GPIO5		17		18	NC	SDX_D1
GND		19		20	GND	
GPIO6		21		22	NC	SDX_D2
GPIO7		23		24	NC	SDX_D3
GND		25		26	GND	
GPIO8		27		28	GPIO28	
GPIO9		29		30	GPIO29	
GND		31		32	GND	
GPIO10		33		34	GPIO30	
GPIO11		35		36	GPIO31	
GND		37		38	GND	
GPIO0-27_VDD		39		40	GPIO0-27_VDD	
		KEY				
GPIO28-45_VDD		41		42	GPIO28-45_VDD	
GND		43		44	GND	
GPIO12		45		46	GPIO32	
GPIO13		47		48	GPIO33	
GND		49		50	GND	
GPIO14		51		52	GPIO34	
GPIO15		53		54	GPIO35	
GND		55		56	GND	
GPIO16		57		58	GPIO36	
GPIO17		59		60	GPIO37	
GND		61		62	GND	
GPIO18		63		64	GPIO38	
GPIO19		65		66	GPIO39	
GND		67		68	GND	
GPIO20		69		70	GPIO40	
GPIO21		71		72	GPIO41	
GND		73		74	GND	
GPIO22		75		76	GPIO42	
GPIO23		77		78	GPIO43	
GND		79		80	GND	
GPIO24		81		82	GPIO44	
GPIO25		83		84	GPIO45	
GND		85		86	GND	
GPIO26		87		88	HDMI_HPD_N_1V8	
GPIO27		89		90	EMMC_EN_N_1V8	
GND		91		92	GND	
DSI0_DN1		93		94	DSI1_DP0	
DSI0_DP1		95		96	DSI1_DN0	
GND		97		98	GND	
DSI0_DN0		99		100	DSI1_CP	
DSI0_DP0		101		102	DSI1_CN	
GND		103		104	GND	
DSI0_CN		105		106	DSI1_DP3	
DSI0_CP		107		108	DSI1_DN3	
GND		109		110	GND	
HDMI_CLK_N		111		112	DSI1_DP2	
HDMI_CLK_P		113		114	DSI1_DN2	
GND		115		116	GND	
HDMI_D0_N		117		118	DSI1_DP1	
HDMI_D0_P		119		120	DSI1_DN1	
GND		121		122	GND	
HDMI_D1_N		123		124	NC	
HDMI_D1_P		125		126	NC	
GND		127		128	NC	
HDMI_D2_N		129		130	NC	
HDMI_D2_P		131		132	NC	
GND		133		134	GND	
CAM1_DP3		135		136	CAM0_DP0	
CAM1_DN3		137		138	CAM0_DN0	
GND		139		140	GND	
CAM1_DP2		141		142	CAM0_CP	
CAM1_DN2		143		144	CAM0_CN	
GND		145		146	GND	
CAM1_CP		147		148	CAM0_DP1	
CAM1_CN		149		150	CAM0_DN1	
GND		151		152	GND	
CAM1_DP1		153		154	NC	
CAM1_DN1		155		156	NC	
GND		157		158	NC	
CAM1_DP0		159		160	NC	
CAM1_DN0		161		162	NC	
GND		163		164	GND	
USB_DP		165		166	TVDAC	
USB_DM		167		168	USB_OTGID	
GND		169		170	GND	
HDMI_CEC		171		172	VC_TRST_N	
HDMI_SDA		173		174	VC_TDI	
HDMI_SCL		175		176	VC_TMS	
RUN		177		178	VC_TDO	
DD_CORE (DO NOT CONNEC		179		180	VC_TCK	
GND		181		182	GND	
1V8		183		184	1V8	
1V8		185		186	1V8	
GND		187		188	GND	
VDAC		189		190	VDAC	
3V3		191		192	3V3	
3V3		193		194	3V3	
GND		195		196	GND	
VBAT		197		198	VBAT	
VBAT		199		200	VBAT	

Table 2: Compute Module 3+ SODIMM Connector Pinout

Table 2 gives the Compute Module 3+ pinout and Table 3 gives the pin functions.

Pin Name	DIR	Voltage Ref	PDN[a] State	If Unused	Description/Notes
RUN and Boot Control (see text for usage guide)					
RUN	I	3V3[b]	Pull High	Leave open	Has internal 10k pull up
EMMC_DISABLE_N	I	3V3[b]	Pull High	Leave open	Has internal 10k pull up
EMMC_EN_N_1V8	O	1V8	Pull High	Leave open	Has internal 2k2 pull up
GPIO					
GPIO[27:0]	I/O	GPIO0-27_VDD	Pull or Hi-Z[c]	Leave open	GPIO Bank 0
GPIO[45:28]	I/O	GPIO28-45_VDD	Pull or Hi-Z[c]	Leave open	GPIO Bank 1
Primary SD Interface[d,e]					
SDX_CLK	O	SDX_VDD	Pull High	Leave open	Primary SD interface CLK
SDX_CMD	I/O	SDX_VDD	Pull High	Leave open	Primary SD interface CMD
SDX_Dx	I/O	SDX_VDD	Pull High	Leave open	Primary SD interface DATA
USB Interface					
USB_Dx	I/O	-	Z	Leave open	Serial interface
USB_OTGID	I	3V3		Tie to GND	OTG pin detect
HDMI Interface					
HDMI_SCL	I/O	3V3[b]	Z[f]	Leave open	DDC Clock (5.5V tolerant)
HDMI_SDA	I/O	3V3[b]	Z[f]	Leave open	DDC Data (5.5V tolerant)
HDMI_CEC	I/O	3V3	Z	Leave open	CEC (has internal 27k pull up)
HDMI_CLKx	O	-	Z	Leave open	HDMI serial clock
HDMI_Dx	O	-	Z	Leave open	HDMI serial data
HDMI_HPD_N_1V8	I	1V8	Pull High	Leave open	HDMI hotplug detect
CAM0 (CSI0) 2-lane Interface					
CAM0_Cx	I	-	Z	Leave open	Serial clock
CAM0_Dx	I	-	Z	Leave open	Serial data
CAM1 (CSI1) 4-lane Interface					
CAM1_Cx	I	-	Z	Leave open	Serial clock
CAM1_Dx	I	-	Z	Leave open	Serial data
DSI0 (Display 0) 2-lane Interface					
DSI0_Cx	O	-	Z	Leave open	Serial clock
DSI0_Dx	O	-	Z	Leave open	Serial data
DSI1 (Display 1) 4-lane Interface					
DSI1_Cx	O	-	Z	Leave open	Serial clock
DSI1_Dx	O	-	Z	Leave open	Serial data
TV Out					
TVDAC	O	-	Z	Leave open	Composite video DAC output
JTAG Interface					
TMS	I	3V3	Z	Leave open	Has internal 50k pull up
TRST_N	I	3V3	Z	Leave open	Has internal 50k pull up
TCK	I	3V3	Z	Leave open	Has internal 50k pull up
TDI	I	3V3	Z	Leave open	Has internal 50k pull up
TDO	O	3V3	O	Leave open	Has internal 50k pull up

[a] The PDN column indicates power-down state (when RUN pin LOW)
[b] Must be driven by an open-collector driver
[c] GPIO have software enabled pulls which keep state over power-down
[d] Only available on Lite variants
[e] The CM will always try to boot from this interface first
[f] Requires external pull-up resistor to 5V as per HDMI spec

Table 3: Pin Functions

6 Electrical Specification

Caution! Stresses above those listed in Table 4 may cause permanent damage to the device. This is a stress rating only; functional operation of the device under these or any other conditions above those listed in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Symbol	**Parameter**	**Minimum**	**Maximum**	**Unit**
VBAT	Core SMPS Supply	-0.5	6.0	V
3V3	3V3 Supply Voltage	-0.5	4.10	V
1V8	1V8 Supply Voltage	-0.5	2.10	V
VDAC	TV DAC Supply	-0.5	4.10	V
GPIO0-27_VDD	GPIO0-27 I/O Supply Voltage	-0.5	4.10	V
GPIO28-45_VDD	GPIO28-45 I/O Supply Voltage	-0.5	4.10	V
SDX_VDD	Primary SD/eMMC Supply Voltage	-0.5	4.10	V

Table 4: Absolute Maximum Ratings

DC Characteristics are defined in Table 5

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Unit
V_{IL}	Input low voltage[a]	VDD_IO = 1.8V	-	-	0.6	V
		VDD_IO = 2.7V	-	-	0.8	V
		VDD_IO = 3.3V	-	-	0.9	V
V_{IH}	Input high voltage[a]	VDD_IO = 1.8V	1.0	-	-	V
		VDD_IO = 2.7V	1.3	-	-	V
		VDD_IO = 3.3V	1.6	-	-	V
I_{IL}	Input leakage current	TA = +85°C	-	-	5	μA
C_{IN}	Input capacitance	-	-	5	-	pF
V_{OL}	Output low voltage[b]	VDD_IO = 1.8V, IOL = -2mA	-	-	0.2	V
		VDD_IO = 2.7V, IOL = -2mA	-	-	0.15	V
		VDD_IO = 3.3V, IOL = -2mA	-	-	0.14	V
V_{OH}	Output high voltage[b]	VDD_IO = 1.8V, IOH = 2mA	1.6	-	-	V
		VDD_IO = 2.7V, IOH = 2mA	2.5	-	-	V
		VDD_IO = 3.3V, IOH = 2mA	3.0	-	-	V
I_{OL}	Output low current[c]	VDD_IO = 1.8V, VO = 0.4V	12	-	-	mA
		VDD_IO = 2.7V, VO = 0.4V	17	-	-	mA
		VDD_IO = 3.3V, VO = 0.4V	18	-	-	mA
I_{OH}	Output high current[c]	VDD_IO = 1.8V, VO = 1.4V	10	-	-	mA
		VDD_IO = 2.7V, VO = 2.3V	16	-	-	mA
		VDD_IO = 3.3V, VO = 2.3V	17	-	-	mA
R_{PU}	Pullup resistor	-	50	-	65	kΩ
R_{PD}	Pulldown resistor	-	50	-	65	kΩ

[a] Hysteresis enabled
[b] Default drive strength (8mA)
[c] Maximum drive strength (16mA)

Table 5: DC Characteristics

AC Characteristics are defined in Table 6 and Fig. 3.

Pin Name	Symbol	Parameter	Minimum	Typical	Maximum	Unit
Digital outputs	t_{rise}	10-90% rise time[a]	-	1.6	-	ns
Digital outputs	t_{fall}	90-10% fall time[a]	-	1.7	-	ns
GPCLK	t_{JOSC}	Oscillator-derived GPCLK cycle-cycle jitter (RMS)	-	-	20	ps
GPCLK	t_{JPLL}	PLL-derived GPCLK cycle-cycle jitter (RMS)	-	-	48	ps

[a] Default drive strength, CL = 5pF, VDD_IOx = 3.3V

Table 6: Digital I/O Pin AC Characteristics

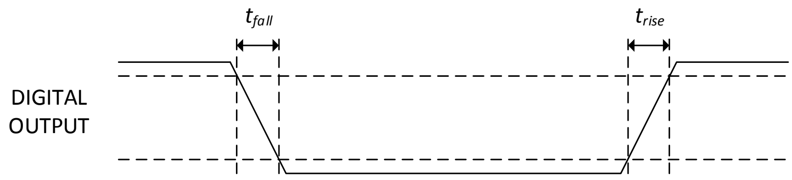


Figure 3: Digital IO Characteristics

7 Power Supplies

The Compute Module 3+ has six separate supplies that must be present and powered at all times; you cannot leave any of them unpowered, even if a specific interface or GPIO bank is unused. The six supplies are as follows:

1. VBAT is used to power the BCM2837 processor core. It feeds the SMPS that generates the chip core voltage.
2. 3V3 powers various BCM2837 PHYs, IO and the eMMC Flash.
3. 1V8 powers various BCM2837 PHYs, IO and SDRAM.
4. VDAC powers the composite (TV-out) DAC.
5. GPIO0-27_VREF powers the GPIO 0-27 IO bank.
6. GPIO28-45_VREF powers the GPIO 28-45 IO bank.

Supply	Descripion	Minimum	Typical	Maximum	Unit
VBAT	Core SMPS Supply	2.5	-	5.0 + 5%	V
3V3	3V3 Supply Voltage	3.3 - 5%	3.3	3.3 + 5%	V
1V8	1V8 Supply Voltage	1.8 - 5%	1.8	1.8 + 5%	V
VDAC	TV DAC Supply[a]	2.5 - 5%	2.8	3.3 + 5%	V
GPIO0-27_VDD	GPIO0-27 I/O Supply Voltage	1.8 - 5%	-	3.3 + 5%	V
GPIO28-45_VDD	GPIO28-45 I/O Supply Voltage	1.8 - 5%	-	3.3 + 5%	V
SDX_VDD	Primary SD/eMMC Supply Voltage	1.8 - 5%	-	3.3 + 5%	V

[a] Requires a clean 2.5-2.8V supply if TV DAC is used, else connect to 3V3

Table 7: Power Supply Operating Ranges

7.1 Supply Sequencing

Supplies should be staggered so that the highest voltage comes up first, then the remaining voltages in descending order. This is to avoid forward biasing internal (on-chip) diodes between supplies, and causing latch-up. Alternatively supplies can be synchronised to come up at exactly the same time as long as at no point a lower voltage supply rail voltage exceeds a higher voltage supply rail voltage.

7.2 Power Requirements

Exact power requirements will be heavily dependent upon the individual use case. If an on-chip subsystem is unused, it is usually in a low power state or completely turned off. For instance, if your application does not use 3D graphics then a large part of the core digital logic will never turn on and need power. This is also the case for camera and display interfaces, HDMI, USB interfaces, video encoders and decoders, and so on.

Powerchain design is critical for stable and reliable operation of the Compute Module 3+. We strongly recommend that designers spend time measuring and verifying power requirements for their particular use case and application, as well as paying careful attention to power supply sequencing and maximum supply voltage tolerance.

Table 8 specifies the recommended minimum power supply outputs required to power the Compute Module 3+.

Supply	Minimum Requirement	Unit
VBAT (CM1)	2000[a]	mW
VBAT (CM3,3L)	3500[a]	mW
3V3	250	mA
1V8	250	mA
VDAC	25	mA
GPIO0-27_VDD	50[b]	mA
GPIO28-45_VDD	50[b]	mA
SDX_VDD	50[b]	mA

[a] Recommended minimum. Actual power drawn is very dependent on use-case
[b] Each GPIO can supply up to 16mA, aggregate current per bank must not exceed 50mA

Table 8: Mimimum Power Supply Requirements

8 Booting

The eMMC Flash device on CM3+ is directly connected to the primary BCM2837 SD/eMMC interface. These connections are not accessible on the module pins. On CM3+ Lite this SD interface is available on the SDX_ pins.

When initially powered on, or after the RUN pin has been held low and then released, the BCM2837 will try to access the primary SD/eMMC interface. It will then look for a file called bootcode.bin on the primary partition (which must be FAT) to start booting the system. If it cannot access the SD/eMMC device or the boot code cannot be found, it will fall back to waiting for boot code to be written to it over USB; in other words, its USB port is in slave mode waiting to accept boot code from a suitable host.

A USB boot tool is available on Github which allows a host PC running Linux to write the BCM2837 boot code over USB to the module. That boot code then runs and provides access to the SD/eMMC as a USB mass storage device, which can then be read and written using the host PC. Note that a Raspberry Pi can be used as the host machine. For those using Windows a precompiled and packeged tool is available. For more information see here.

The Compute Module has a pin called EMMC_DISABLE_N which when shorted to GND will disable the SD/eMMC interface (by physically disconnecting the SD_CMD pin), forcing BCM2837 to boot from USB. Note that when the eMMC is disabled in this way, it takes a couple of seconds from powering up for the processor to stop attempting to talk to the SD/eMMC device and fall back to booting from USB.

Note that once booted over USB, BCM2837 needs to re-enable the SD/eMMC device (by releasing EMMC_DISABLE_N) to allow access to it as mass storage. It expects to be able to do this by driving the EMMC_EN_N_1V8 pin LOW, which at boot is initially an input with a pull up to 1V8. If an end user wishes to add the ability to access the SD/eMMC over USB in their product, similar circuitry to that used on the Compute Module IO Board to enable/disable the USB boot and SD/eMMC must be used; that is, EMMC_DISABLE_N pulled low via MOSFET(s) and released again by MOSFET, with the gate controlled by EMMC_EN_N_1V8. **Ensure you use MOSFETs suitable for switching at 1.8V (i.e. use a device with gate threshold voltage, Vt, suitable for 1.8V switching).**

9 Peripherals

9.1 GPIO

BCM2837 has in total 54 GPIO lines in 3 separate voltage banks. All GPIO pins have at least two alternative functions within the SoC. When not used for the alternate peripheral function, each GPIO pin may be set as an input (optionally as an interrupt) or an output. The alternate functions are usually peripheral I/Os, and most peripherals appear twice to allow flexibility on the choice of I/O voltage.

GPIO bank2 is used on the module to connect to the eMMC device and for an on-board I2C bus (to talk to the core SMPS and control the special function pins). On CM3+ Lite most of bank2 is exposed to allow a user to connect their choice of SD card or eMMC device (if required).

Bank0 and 1 GPIOs are available for general use. GPIO0 to GPIO27 are bank0 and GPIO28-45 make up bank1. GPIO0-27_VDD is the power supply for bank0 and GPIO28-45_VDD is the power supply for bank1. SDX_VDD is the supply for bank2 on CM3+ Lite. These supplies can be in the range 1.8V-3.3V (see Table 7) and are not optional; each bank must be powered, even when none of the GPIOs for that bank are used.

Note that the HDMI_HPD_N_1V8 and EMMC_EN_N_1V8 pins are 1.8V IO and are used for special functions (HDMI hot plug detect and boot control respectively). Please do not use these pins for any other purpose, as the software for the module will always expect these pins to have these special functions. If they are unused please leave them unconnected.

All GPIOs except GPIO28, 29, 44 and 45 have weak in-pad pull-ups or pull-downs enabled when the device is powered on. It is recommended to add off-chip pulls to GPIO28, 29, 44 and 45 to make sure they never float during power on and initial boot.

9.1.1 GPIO Alternate Functions

GPIO	Default Pull	ALT0	ALT1	ALT2	ALT3	ALT4	ALT5
0	High	SDA0	SA5	PCLK	-	-	-
1	High	SCL0	SA4	DE	-	-	-
2	High	SDA1	SA3	LCD_VSYNC	-	-	-
3	High	SCL1	SA2	LCD_HSYNC	-	-	-
4	High	GPCLK0	SA1	DPI_D0	-	-	ARM_TDI
5	High	GPCLK1	SA0	DPI_D1	-	-	ARM_TDO
6	High	GPCLK2	SOE_N	DPI_D2	-	-	ARM_RTCK
7	High	SPI0_CE1_N	SWE_N	DPI_D3	-	-	-
8	High	SPI0_CE0_N	SD0	DPI_D4	-	-	-
9	Low	SPI0_MISO	SD1	DPI_D5	-	-	-
10	Low	SPI0_MOSI	SD2	DPI_D6	-	-	-
11	Low	SPI0_SCLK	SD3	DPI_D7	-	-	-
12	Low	PWM0	SD4	DPI_D8	-	-	ARM_TMS
13	Low	PWM1	SD5	DPI_D9	-	-	ARM_TCK
14	Low	TXD0	SD6	DPI_D10	-	-	TXD1
15	Low	RXD0	SD7	DPI_D11	-	-	RXD1
16	Low	FL0	SD8	DPI_D12	CTS0	SPI1_CE2_N	CTS1
17	Low	FL1	SD9	DPI_D13	RTS0	SPI1_CE1_N	RTS1
18	Low	PCM_CLK	SD10	DPI_D14	-	SPI1_CE0_N	PWM0
19	Low	PCM_FS	SD11	DPI_D15	-	SPI1_MISO	PWM1
20	Low	PCM_DIN	SD12	DPI_D16	-	SPI1_MOSI	GPCLK0
21	Low	PCM_DOUT	SD13	DPI_D17	-	SPI1_SCLK	GPCLK1
22	Low	SD0_CLK	SD14	DPI_D18	SD1_CLK	ARM_TRST	-
23	Low	SD0_CMD	SD15	DPI_D19	SD1_CMD	ARM_RTCK	-
24	Low	SD0_DAT0	SD16	DPI_D20	SD1_DAT0	ARM_TDO	-
25	Low	SD0_DAT1	SD17	DPI_D21	SD1_DAT1	ARM_TCK	-
26	Low	SD0_DAT2	TE0	DPI_D22	SD1_DAT2	ARM_TDI	-
27	Low	SD0_DAT3	TE1	DPI_D23	SD1_DAT3	ARM_TMS	-

Table 9: GPIO Bank0 Alternate Functions

GPIO	Default Pull	ALT0	ALT1	ALT2	ALT3	ALT4	ALT5
28	None	SDA0	SA5	PCM_CLK	FL0	-	-
29	None	SCL0	SA4	PCM_FS	FL1	-	-
30	Low	TE0	SA3	PCM_DIN	CTS0	-	CTS1
31	Low	FL0	SA2	PCM_DOUT	RTS0	-	RTS1
32	Low	GPCLK0	SA1	RING_OCLK	TXD0	-	TXD1
33	Low	FL1	SA0	TE1	RXD0	-	RXD1
34	High	GPCLK0	SOE_N	TE2	SD1_CLK	-	-
35	High	SPI0_CE1_N	SWE_N	-	SD1_CMD	-	-
36	High	SPI0_CE0_N	SD0	TXD0	SD1_DAT0	-	-
37	Low	SPI0_MISO	SD1	RXD0	SD1_DAT1	-	-
38	Low	SPI0_MOSI	SD2	RTS0	SD1_DAT2	-	-
39	Low	SPI0_SCLK	SD3	CTS0	SD1_DAT3	-	-
40	Low	PWM0	SD4	-	SD1_DAT4	SPI2_MISO	TXD1
41	Low	PWM1	SD5	TE0	SD1_DAT5	SPI2_MOSI	RXD1
42	Low	GPCLK1	SD6	TE1	SD1_DAT6	SPI2_SCLK	RTS1
43	Low	GPCLK2	SD7	TE2	SD1_DAT7	SPI2_CE0_N	CTS1
44	None	GPCLK1	SDA0	SDA1	TE0	SPI2_CE1_N	-
45	None	PWM1	SCL0	SCL1	TE1	SPI2_CE2_N	-

Table 10: GPIO Bank1 Alternate Functions

Table 9 and Table 10 detail the default pin pull state and available alternate GPIO functions. Most of these alternate peripheral functions are described in detail in the Broadcom Peripherals Specification document and have Linux drivers available.

9.1.2 Secondary Memory Interface (SMI)

The SMI peripheral is an asynchronous NAND type bus supporting Intel mode80 type transfers at 8 or 16 bit widths and available in the ALT1 positions on GPIO banks 0 and 1 (see Table 9 and Table 10). It is not publicly documented in the Broadcom Peripherals Specification but a Linux driver is available in the Raspberry Pi Github Linux repository (bcm2835_smi.c in linux/drivers/misc).

9.1.3 Display Parallel Interface (DPI)

A standard parallel RGB (DPI) interface is available on bank 0 GPIOs. This up-to-24-bit parallel interface can support a secondary display. Again this interface is not documented in the Broadcom Peripherals Specification but documentation can be found here.

9.1.4 SD/SDIO Interface

The BCM283x supports two SD card interfaces, SD0 and SD1.

The first (SD0) is a proprietary Broadcom controller that does not support SDIO and is the primary interface used to boot and talk to the eMMC or SDX_x signals.

The second interface (SD1) is standards compliant and can interface to SD, SDIO and eMMC devices; for example on a Raspberry Pi 3 B+ it is used to talk to the on-board CYW43455 WiFi device in SDIO mode.

Both interfaces can support speeds up to 50MHz single ended (SD High Speed Mode).

9.2 CSI (MIPI Serial Camera)

Currently the CSI interface is not openly documented and only CSI camera sensors supported by the official Raspberry Pi firmware will work with this interface. Supported sensors are the OmniVision OV5647 and Sony IMX219.

It is recommended to attach other cameras via USB.

9.3 DSI (MIPI Serial Display)

Currently the DSI interface is not openly documented and only DSI displays supported by the official Raspberry Pi firmware will work with this interface.

Displays can also be added via the parallel DPI interface which is available as a GPIO alternate function - see Table 9 and Section 9.1.3

9.4 USB

The BCM2837 USB port is On-The-Go (OTG) capable. If using either as a fixed slave or fixed master, please tie the USB_OTGID pin to ground.

The USB port (Pins USB_DP and USB_DM) must be routed as 90 ohm differential PCB traces.

Note that the port is capable of being used as a true OTG port however there is no official documentation. Some users have had success making this work.

9.5 HDMI

BCM283x supports HDMI V1.3a.

It is recommended that users follow a similar arrangement to the Compute Module IO Board circuitry for HDMI output.

The HDMI CK_P/N (clock) and D0-D2_P/N (data) pins must each be routed as matched length 100 ohm differential PCB traces. It is also important to make sure that each differential pair is closely phase matched. Finally, keep HDMI traces well away from other noise sources and as short as possible.

Failure to observe these design rules is likely to result in EMC failure.

9.6 Composite (TV Out)

The TVDAC pin can be used to output composite video (PAL or NTSC). Please route this signal away from noise sources and use a 75 ohm PCB trace.

Note that the TV DAC is powered from the VDAC supply which must be a clean supply of 2.5-2.8V. It is recommended users generate this supply from 3V3 using a low noise LDO.

If the TVDAC output is not used VDAC can be connected to 3V3, but it must be powered even if the TV-out functionality is unused.

10 Thermals

The BCM2837 SoC employs DVFS (Dynamic Voltage and Frequency Scaling) on the core voltage. When the processor is idle (low CPU utilisation), it will reduce the core frequency and voltage to reduce current draw and heat output. When the core utilisation exceeds a certain threshold the core votlage is increased and the core frequency is boosted to the maximum working frerquency of 1.2GHz. The voltage and frequency are throttled back when the CPU load reduces back to an 'idle' level OR when the silicon temperature as mesured by the on-chip temperature sensor exceeds 80C (thermal throttling).

A designer must pay careful attention to the thermal design of products using the CM3+ so that performance is not artificially curtailed due to the processor thermal throttling, as the Quad ARM complex in the BCM2837 can generate significant heat output under load.

10.1 Temperature Range

The operating temperature range of the module is set by the lowest maximum and highest minimum of any of the components used.

The eMMC and LPDDR2 have the narrowest range, these are rated for -25 to +80 degrees Celsius. Therefore the nominal range for the CM3+ and CM3+ Lite is -25C to +80C.

However, this range is the maximum for the silicon die; therefore, users would have to take into account the heat generated when in use and make sure this does not cause the temperature to exceed 80 degrees Celsius.

11 Availability

Raspberry Pi guarantee availability of CM3+ and CM3+ Lite until at least January 2026.

12 Support

For support please see the hardware documentation section of the Raspberry Pi website and post questions to the Raspberry Pi forum.

Appendix B

Final Project Presentation

Talkative

sign language to speech convertor

RSET
RAJAGIRI SCHOOL OF ENGINEERING & TECHNOLOGY

Applied Electronics and Instrumentation
Final year project presentation

Team:

Arjun M B

M K Arun

Mathew K Joshi

Guide:
Ms. Priya S


Outline
INTRODUCTION
OBJECTIVE
PREVIOUS WORK DONE
CURRENT WORK
RESULTS/DISCUSSION
REFERENCES


Introduction
Around 70 million people in this world are mute people. There
Communication between the people with speech impairment and others is very difficult
People with speech impairment use Sign Language to communicate with others.

Objective

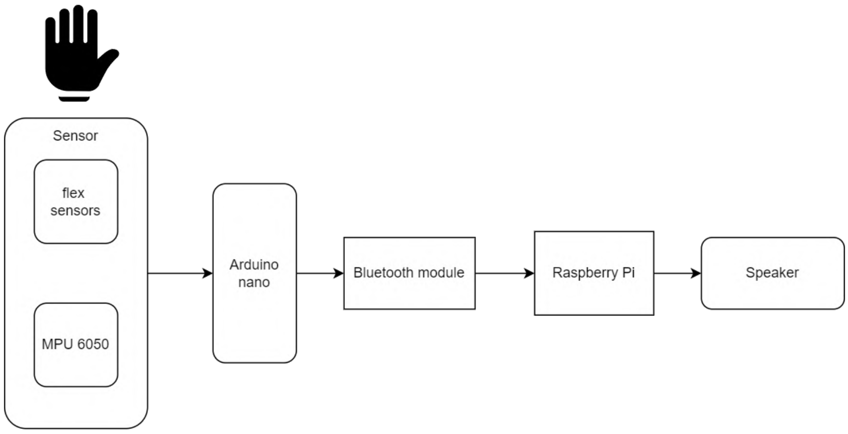
•We aim to design and make a product that can reliably and efficiently convert custom sign-language to communicable english by recognising hand gestures and predicting output.

Tech Stacks Used

MPU 6050
Arduino UNO
Flex Sensors
PAM 8403
DF Player Mini
Speakers

Linear Regression
Random Forest
Support Vector Machine
ANN

Methodology



Methodology

Hand gesture data can be obtained mainly through two methods
i) image recognition
ii) individual finger sensor data

Methodology

The Glove consists of a Flex Sensor and an MPU6050 . Where the flex sensor is used to measure the bend of the finger while the MPU 6050 is used to measure the orientation of the hand

Methodology

Data of the finger movement is obtained through flex sensors between the range of 0 to 1023 ADC values corresponding to 0 to 5V

The flex sensor is basically a variable resistor that increases its resistance as it is bending.

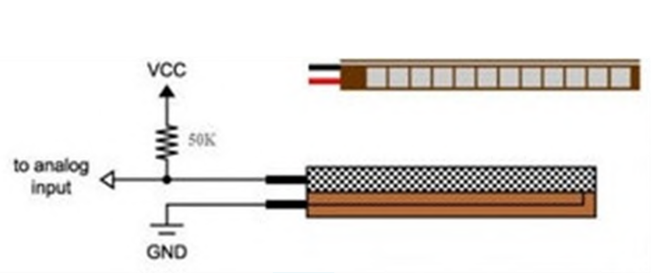
Methodology

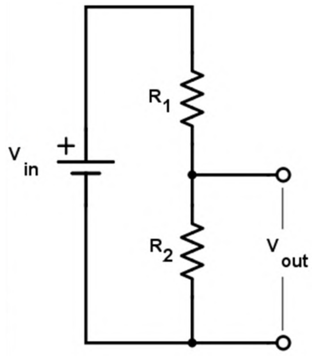
4 flex sensors connected to form a voltage divider circuit.

The basic equation of the voltage divider is;

$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

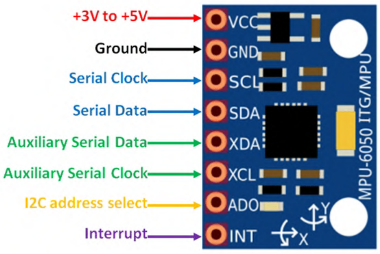
Methodology





Methodology

MPU 6050 sensor is used to get the orientation of the hand. It is a MEMS-based 6-axis motion tracking device. It has an on-chip gyroscope and accelerometer sensors along with a temperature sensor



Methodology

We created a C program to recognise the sign and translate that into audio which we can hear through a speaker with the help of Dfplayer mini and PAM-8403

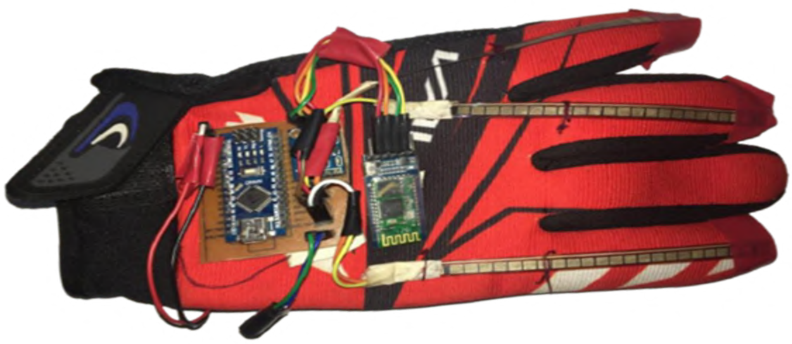
Previous work done

• In the previous semester, we did the literature survey based on our project.

• We also made a prototype of our project using basic if/else condition to recognize the gesture

• project circuit design in proteus

Previous work done



Issues

•Reliability issues was found with the sensor that was being used.

•Values starts to vary over time.

•This problem makes it difficult to create a machine learning model based on the values that we acquire from the sensor

Current Work done

we developed a sensor that can detect bend and gives analogous values corresponding to bend

Made by sandwiching two aluminum strips around a graphite particle layer
bend causes the graphite particles to come closer thus increasing the resistance

this resistance is from 5 fingers are connected to form a potential divider circuit and Vout is taken from each node

Current Work done

Current Work done

Modification

•Use of MPU6050 sensor to overcome the issues caused by the flex sensor.

•Tested the values that comes form MPU 6050,

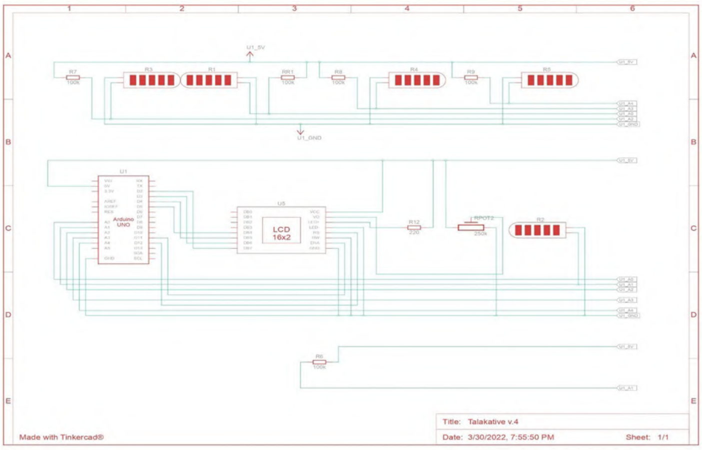
•Issues found with MPU 6050 sensor

•Each sensor requires 2 analog input pins, that will total to 12 analog input pins for 6 sensors

•Only 6 analog inputs are available to use in the microcontroller

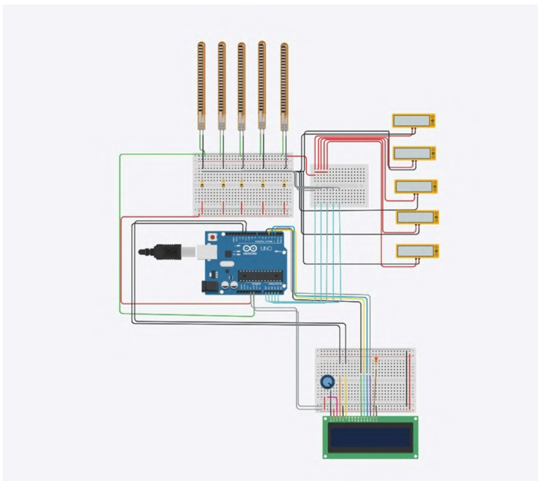
Current Work done

Schematic's of the circuit



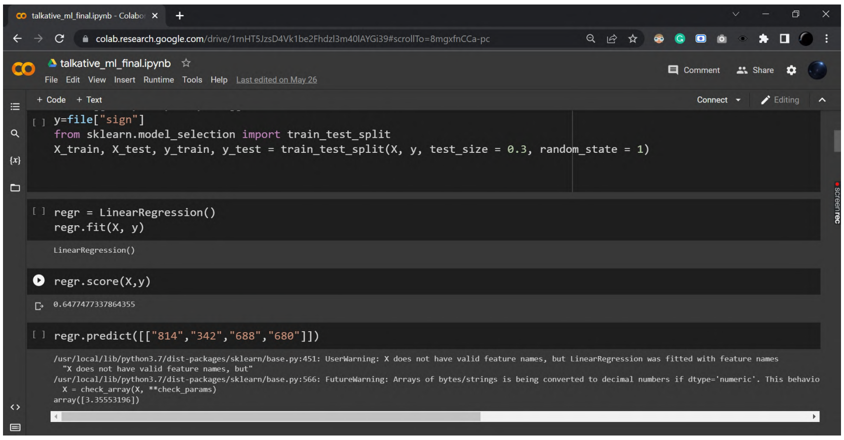
Current Work done

Simulation:



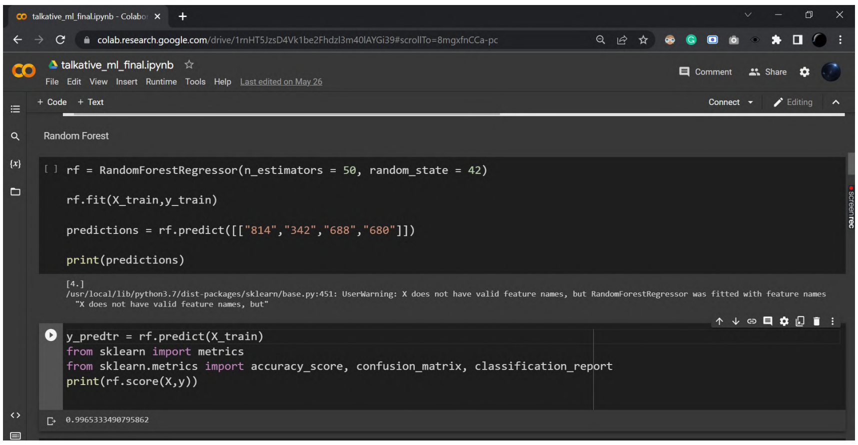
Current Work done

Linear Regression:



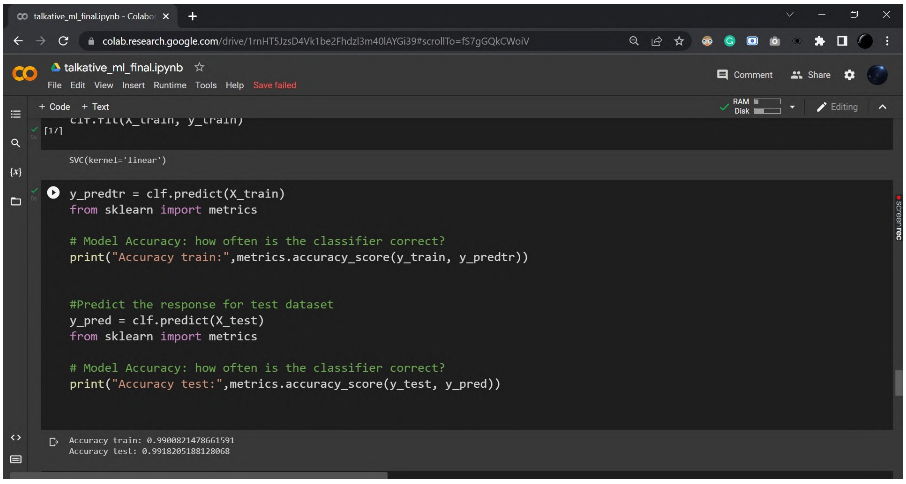
Current Work done

Random Forest:



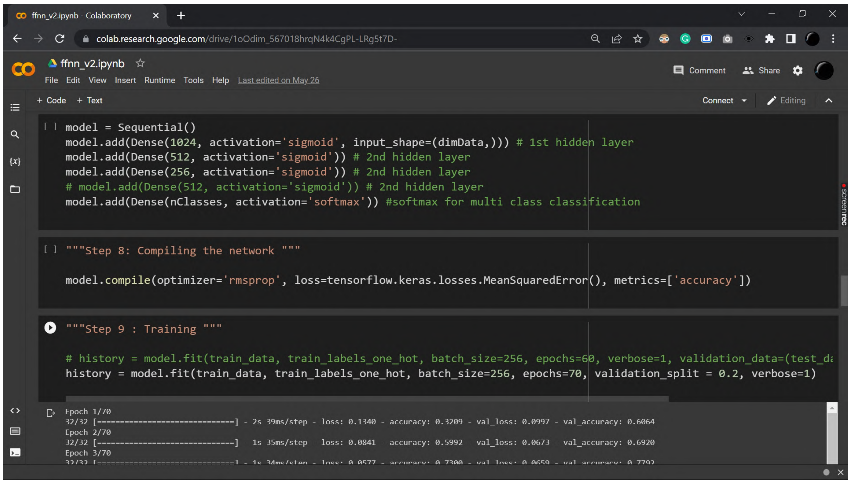
Current Work done

SVM:



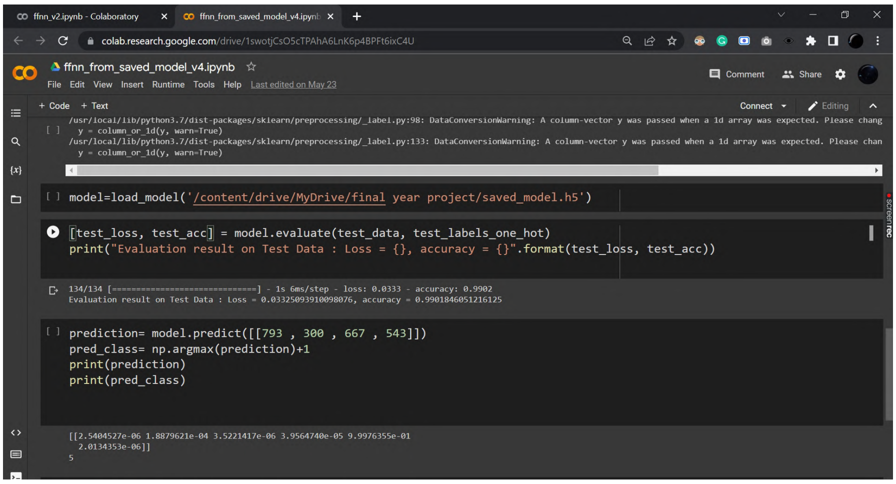
Current Work done

Neural network:



Current Work done

Neural network: Saved model



Result

Random Forest:

Score	0.996
Mean Absolute Error	0.011
Mean Squared Error	0.03
Root Mean Squared Error	0.173

Result

SVM:

Linear Kernel

Test accuracy	99.1
train accuracy	99.0

Radial base function Kernel

Test accuracy	98.7
train accuracy	98.5

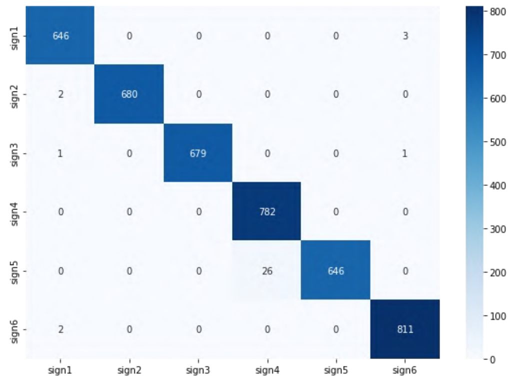
Polynomial Kernel

Test accuracy	99.15
train accuracy	99.0

Result

SVM:

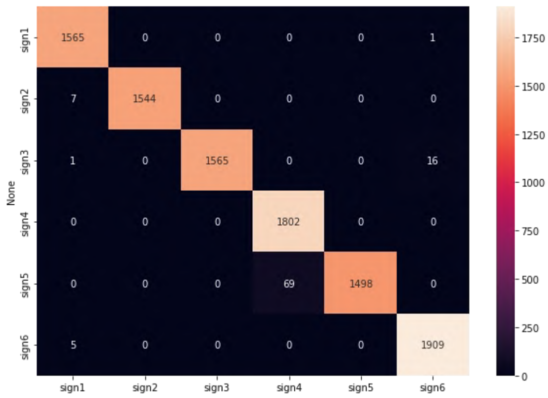
test_confusion_matrix



Result

SVM:

train_confusion_matrix



Result

SVM:

classification_report

	precision	recall	f1-score	support
1	0.99	1.00	0.99	649
2	1.00	1.00	1.00	682
3	1.00	1.00	1.00	681
4	0.97	1.00	0.98	782
5	1.00	0.96	0.98	672
6	1.00	1.00	1.00	813
accuracy			0.99	4279
macro avg	0.99	0.99	0.99	4279
weighted avg	0.99	0.99	0.99	4279

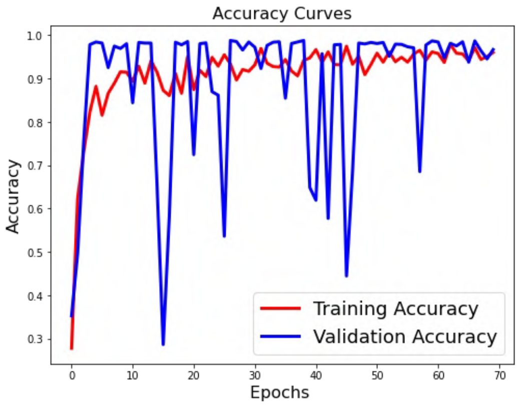
Result

Neural network:

Loss	0.33
accuracy	99.01

Result

Neural network:



Result

- M. Georgi, C. Amma, and T. Schultz, "Recognizing hand and finger gestures with imu based motion and EMG based muscle activity sensing." in Biosignals. Citeseer, 2015, pp. 99–108..
- M. Ariyanto, W. Caesarendra, K. A. Mustaqim, M. Irfan, J. A. Pakpahan, J. D. Setiawan, and A. R. Winoto, "Finger movement pattern recognition method using artificial neural network based on electromyography (emg) sensor," in 2015 International Conference on Automation, Cognitive Science, Optics, Micro Electro-Mechanical System, and Information Technology (ICACOMIT). IEEE,
- C. Jorgensen, D. D. Lee, and S. Agabont, "Sub auditory speech recognition based on emg signals," in Proceedings of the International Joint Conference on Neural Networks, 2003., vol. 4. IEEE, 2003, pp. 3128–3133. 2015, pp. 12–17.

Result

- X. Zhang, X. Chen, Y. Li, V. Lantz, K. Wang, and J. Yang, "A framework for hand gesture recognition based on accelerometer and emg sensors," IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans, vol. 41, no. 6, pp. 1064–1076, 2011.
- P. D. Rosero-Montalvo, P. Godoy-Trujillo, E. Flores-Bosmediano, J. Carrascal-Garcia, S. Otero-Potosi, H. Benitez-Pereira, and D. H. Peluffo-Ordonez, "Sign language recognition based on intelligent glove using machine learning techniques," in 2018 IEEE Third Ecuador Technical Chapters Meeting (ETCM). IEEE, 2018, pp. 1–5
- X. Chu, J. Liu, and S. Shimamoto, "A sensor-based hand gesture recognition system for japanese sign language," in 2021 IEEE 3rd Global Conference on Life Sciences and Technologies (LifeTech). IEEE, 2021, pp. 311–312

Thank you

Appendix C

Code

C.1 Nueral Network

```
# -*- coding: utf-8 -*-
"""ffnn_v2.ipynb

Automatically generated by Colaboratory.

Original file is located at
    https://colab.research.google.com/drive/1o0dim_567018hrqN4k4CgPL-LRg5t7D-
"""

import tensorflow
from tensorflow import keras
from sklearn.model_selection import train_test_split
# from keras.datasets import mnist
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd



from keras.models import Sequential
from keras.layers import Dense, Dropout
from keras.wrappers.scikit_learn import KerasClassifier
from sklearn.model_selection import cross_val_score
```

```
from sklearn.preprocessing import LabelEncoder
from sklearn.model_selection import StratifiedKFold
from sklearn.preprocessing import StandardScaler
from sklearn.pipeline import Pipeline
from sklearn.model_selection import train_test_split
from keras.utils import np_utils
from sklearn.model_selection import KFold
from sklearn.metrics import confusion_matrix
import itertools

from google.colab import drive
drive.mount('/content/drive')

file=pd.read_csv("/content/drive/MyDrive/final year project/Document from am.arjun")
X=file[["f1","f2","f3","f4"]]
y=file[["sign"]]

print(X)

from sklearn.model_selection import train_test_split

train_data, test_data, train_labels, test_labels = train_test_split(X, y, test_size = 0.3, random_state = 1)

"""Step 2: Understand the dataset Shape"""

# from tensorflow.keras.utils import to_categorical as cat
print('Training data shape : ', train_data.shape, train_labels.shape)
print('Testing data shape : ', test_data.shape, test_labels.shape)

dimData = np.prod(train_data.shape[1:])
# train_data = train_data.reshape(train_data.shape[0], dimData) #reshape train data
# test_data = test_data.reshape(test_data.shape[0], dimData) #reshape test data

```

```
# Find the unique numbers from the train labels
classes = np.unique(train_labels) #CHecks for unique labels in
    the traning labels
nClasses = len(classes) #length of the output
print('Total number of outputs : ', nClasses)
print('Output classes : ', classes)

# Change the labels from integer to categorical data
encoder = LabelEncoder()
encoder.fit(train_labels)
encoded_train_labels = encoder.transform(train_labels)
encoded_train_labels = np_utils.to_categorical(
    encoded_train_labels)
# print("encoded_train_labels=", encoded_train_labels)


encoder.fit(test_labels)
encoded_test_labels = encoder.transform(test_labels)

encoded_test_labels = np_utils.to_categorical(
    encoded_test_labels)
# print("encoded_test_labels=", encoded_test_labels)

train_labels_one_hot = encoded_train_labels
test_labels_one_hot = encoded_test_labels



#Display the change for category label using one-hot encoding
print('Original label 0 : ', test_labels[:])
print('After conversion to categorical ( one-hot ) : ',
    test_labels_one_hot[0,:])

"""Step 7: Create the Network """

from keras.models import Sequential
from keras.layers import Dense

model = Sequential()
```

```
model.add(Dense(1024, activation='sigmoid', input_shape=(dimData
    ,))) # 1st hidden layer
model.add(Dense(512, activation='sigmoid')) # 2nd hidden layer
model.add(Dense(256, activation='sigmoid')) # 2nd hidden layer
# model.add(Dense(512, activation='sigmoid')) # 2nd hidden layer
model.add(Dense(nClasses, activation='softmax')) #softmax for
    multi class classification

"""Step 8: Compiling the network """

model.compile(optimizer='rmsprop', loss='
    categorical_crossentropy', metrics=['accuracy'])

"""Step 9 : Training """

# history = model.fit(train_data, train_labels_one_hot,
    batch_size=256, epochs=60, verbose=1, validation_data=(
    test_data, test_labels_one_hot))
history = model.fit(train_data, train_labels_one_hot, batch_size
    =256, epochs=70, validation_split = 0.2, verbose=1)

model.save('/content/drive/MyDrive/final year project/
    saved_model.h5')

"""Step 10 : Model Evaluation """

[test_loss, test_acc] = model.evaluate(test_data,
    test_labels_one_hot)
print("Evaluation result on Test Data : Loss = {}, accuracy = {}
    ".format(test_loss, test_acc))

import csv


fields = ['f1', 'f2', 'f3', 'f3','sign']

rows = np.concatenate(test_data, test_labels)


```

```

print(rows)


# name of csv file
filename = "test_records.csv"

# writing to csv file
with open(filename, 'w') as csvfile:
  # creating a csv writer object
  csvwriter = csv.writer(csvfile)

  # writing the fields
  csvwriter.writerow(fields)

  # writing the data rows
  csvwriter.writerows(rows)

"""Step 11 : Check for Overfitting """

#Plot the Loss Curves
plt.figure(figsize=[8,6])
plt.plot(history.history['loss'],'r',linewidth=3.0)
plt.plot(history.history['val_loss'],'b',linewidth=3.0)
plt.legend(['Training loss', 'Validation Loss'],fontsize=18)
plt.xlabel('Epochs ',fontsize=16)
plt.ylabel('Loss',fontsize=16)
plt.title('Loss Curves',fontsize=16)

#Plot the Accuracy Curves
plt.figure(figsize=[8,6])
plt.plot(history.history['accuracy'],'r',linewidth=3.0)
plt.plot(history.history['val_accuracy'],'b',linewidth=3.0)
plt.legend(['Training Accuracy', 'Validation Accuracy'],fontsize
   =18)
plt.xlabel('Epochs ',fontsize=16)
plt.ylabel('Accuracy',fontsize=16)
plt.title('Accuracy Curves',fontsize=16)

```

```
plt.plot(hist.history['loss'])
plt.plot(hist.history['val_loss'])
plt.title('Model loss')
plt.ylabel('Loss')
plt.xlabel('Epoch')
plt.legend(['Train', 'Val'], loc='upper right')
plt.show()
```

Code to call the trained data so that it can be accesd easly

```
# -*- coding: utf-8 -*-
"""ffnn_from_saved_model_v4.ipynb

Automatically generated by Colaboratory.

Original file is located at
    https://colab.research.google.com/drive/1swotjCsO5cTPAhA6LnK6p4BPFt6ixC4U
"""

import tensorflow
from tensorflow import keras
from keras.models import load_model
from sklearn.model_selection import train_test_split
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
from keras.models import Sequential
from keras.layers import Dense, Dropout
from keras.wrappers.scikit_learn import KerasClassifier
from sklearn.model_selection import cross_val_score
from sklearn.preprocessing import LabelEncoder
from sklearn.model_selection import StratifiedKFold
from sklearn.preprocessing import StandardScaler
from sklearn.pipeline import Pipeline
from sklearn.model_selection import train_test_split
from keras.utils import np_utils
from sklearn.model_selection import KFold
from sklearn.metrics import confusion_matrix

from google.colab import drive
drive.mount('/content/drive')

file=pd.read_csv("/content/drive/MyDrive/final year project/Document from am.arjun")
X=file[["f1","f2","f3","f4"]]
y=file[["sign"]]
train_data, test_data, train_labels, test_labels =
```

```
    train_test_split(X, y, test_size = 0.3, random_state = 1)

encoder = LabelEncoder()
encoder.fit(train_labels)
encoded_train_labels = encoder.transform(train_labels)
encoded_train_labels = np_utils.to_categorical(encoded_train_labels)
# print("encoded_train_labels=", encoded_train_labels)


encoder.fit(test_labels)
encoded_test_labels = encoder.transform(test_labels)

encoded_test_labels = np_utils.to_categorical(encoded_test_labels)
# print("encoded_test_labels=", encoded_test_labels)

train_labels_one_hot = encoded_train_labels
test_labels_one_hot = encoded_test_labels

model=load_model('/content/drive/MyDrive/final year project/saved_model.h5')

[test_loss, test_acc] = model.evaluate(test_data, test_labels_one_hot)
print("Evaluation result on Test Data : Loss = {}, accuracy = {}".format(test_loss, test_acc))

prediction= model.predict([[793 , 300 , 667 , 543]])
pred_class= np.argmax(prediction)+1
print(prediction)
print(pred_class)
```

C.2 Machine Learning

```
# -*- coding: utf-8 -*-
"""talkative_ml_final.ipynb

Automatically generated by Colaboratory.

Original file is located at
    https://colab.research.google.com/drive/1rnHT5JzsD4Vk1be2Fhdzl3m40lAYGi39
"""

import pandas as pd
import numpy as np
import matplotlib_inline
import seaborn as sn
from matplotlib import pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.model_selection import train_test_split
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LinearRegression
from sklearn.ensemble import RandomForestRegressor
from sklearn import metrics

from google.colab import drive
drive.mount('/content/drive')

file=pd.read_csv("/content/drive/MyDrive/final year project/Document from am.arjun")
X=file[["f1","f2","f3","f4"]]
y=file["sign"]
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size = 0.3, random_state = 1)

regr = LinearRegression()
regr.fit(X, y)

regr.score(X,y)
```

```

regr.predict([["814","342","688","680"]])

"""Random Forest"""

rf = RandomForestRegressor(n_estimators = 50, random_state = 42)

rf.fit(X_train,y_train)

predictions = rf.predict([["814","342","688","680"]])

print(predictions)

y_predtr = rf.predict(X_train)
from sklearn import metrics
from sklearn.metrics import accuracy_score, confusion_matrix,
    classification_report
print(rf.score(X,y))

#Predict the response for test dataset
y_pred = rf.predict(X_test)
print('Mean Absolute Error:', metrics.mean_absolute_error(y_test
    , y_pred))
print('Mean Squared Error:', metrics.mean_squared_error(y_test,
    y_pred))
print('Root Mean Squared Error:', np.sqrt(metrics.
    mean_squared_error(y_test, y_pred)))

"""SVM"""

X_train, X_test, y_train, y_test = train_test_split(X, y,
    test_size = 0.3, random_state = 1)
from sklearn import svm

file.head()

import seaborn as sns
print(file.head())
y = file.sign
```

```
X = file.drop('sign',axis=1)
sns.pairplot(file, hue="sign",palette="bright")

df=file
df=df.drop(['f1','f2','f3'], axis=1)
# df.head()
X=df.iloc[:,0:2]
y=df['sign']
sns.scatterplot(X.iloc[:, 0], X.iloc[:, 1], c=y, s=50,legend='
    auto',palette="ch:start=.2,rot=-.3")

df=file
df=df.drop(['f1','f2'], axis=1)
# df.head()
X=df.iloc[:,0:2]
y=df['sign']
sns.scatterplot(X.iloc[:, 0], X.iloc[:, 1], c=y, s=50,legend='
    auto',palette="ch:start=.2,rot=-.3")

df=file
df=df.drop(['f1'], axis=1)
# df.head()
X=df.iloc[:,0:2]
y=df['sign']
sns.scatterplot(X.iloc[:, 0], X.iloc[:, 1], c=y, s=50,legend='
    auto',palette="ch:start=.2,rot=-.3")

df=file
# df.head()
X=df.iloc[:,0:2]
y=df['sign']
plt.scatter(X.iloc[:, 0], X.iloc[:, 1], c=y, s=50, cmap='autumn'
    )
sns.scatterplot(X.iloc[:, 0], X.iloc[:, 1], c=y, s=50,legend='
    auto',palette="ch:start=.2,rot=-.3")

#Create a svm Classifier
# clf = svm.SVC(kernel='poly',degree=6) # Linear Kernel
clf = svm.SVC(kernel='linear') # Linear Kernel
```

```
# clf = SVC(kernel = 'rbf')

#Train the model using the training sets
clf.fit(X_train, y_train)

y_predtr = clf.predict(X_train)
from sklearn import metrics

# Model Accuracy: how often is the classifier correct?
print("Accuracy train:",metrics.accuracy_score(y_train, y_predtr
    ))


#Predict the response for test dataset
y_pred = clf.predict(X_test)
from sklearn import metrics

# Model Accuracy: how often is the classifier correct?
print("Accuracy test:",metrics.accuracy_score(y_test, y_pred))

clf.support_vectors_

predictions = clf.predict([["814","342","688","680"]])
print(predictions)

from sklearn.metrics import confusion_matrix
test_confusion_matrix = confusion_matrix(y_test, y_pred)
print(test_confusion_matrix)

test_cm = pd.DataFrame(testS_confusion_matrix, index = [i for i
    in ["sign1","sign2","sign3","sign4","sign5","sign6"]],columns
    = [i for i in ["sign1","sign2","sign3","sign4","sign5","sign6"
    ]])
plt.figure(figsize = (10,7))
sn.heatmap(test_cm, annot=True,fmt="d",cmap='Blues')

train_confusion_matrix = confusion_matrix(y_train, y_predtr)
print(train_confusion_matrix)

```

```
train_cm = pd.DataFrame(train_confusion_matrix, index = [["sign1
    ","sign2","sign3","sign4","sign5","sign6"]],columns = [i for i
     in ["sign1","sign2","sign3","sign4","sign5","sign6"]])
plt.figure(figsize = (10,7))
sn.heatmap(train_cm, annot=True,fmt="d")

from sklearn.metrics import classification_report
report = classification_report(y_test, y_pred,output_dict=True)
print(classification_report(y_test, y_pred))

df = pd.DataFrame(report)
df.style
```