DEPARTMENT OF PHYSICS, UNIVERSITY OF COLOMBO

GROUP PROJECT

SEMESTER I – 2023

Implementing IoT using Raspberry Pi

NAME: M.A. Shazni Ahmad

INDEX NO: s14784

Abstract

The aim of this project is to build an environmental monitoring and control system, by connecting a Raspberry Pi 3 b module to the world of IoT. Integrating a DHT11 sensor, 1-channel 5V relay, and an LED, the system effectively measures temperature and humidity in real-time. Automation is achieved through relay control, allowing the activation of external devices based on specific humidity or temperature thresholds. The Raspberry Pi's console displays real-time sensor data, providing instant visualization. Additionally, data is published to a remote Mosquitto MQTT broker, enabling remote monitoring. The project further establishes a PostgreSQL database to log received sensor data and relay status for historical analysis. The successful implementation of the system allows for practical environmental monitoring and offers potential for broader applications in various fields.

Table of Contents

1. Introduction

Raspberry Pi is a powerful tool that is widely used in the professional world for various purposes. The motive of implementing this sort of a project was to familiarize with the use of Raspberry Pi in order to connect with IoT. This environmental monitoring and control system is an innovative project aimed at utilizing the capabilities of the Raspberry Pi 3 B module to monitor environmental parameters and implement control actions based on the gathered data. The primary focus of this project was to integrate a DHT11 temperature and humidity sensor, a 1-channel 5V relay, and an LED with the Raspberry Pi to create a versatile and responsive system.

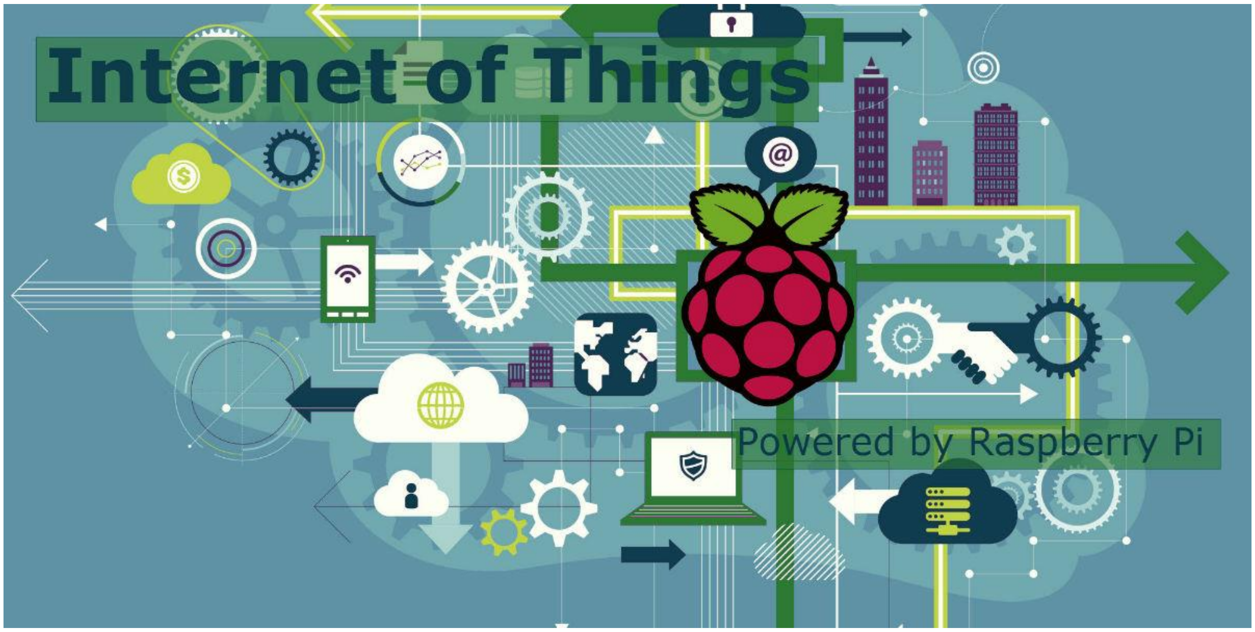

Figure 1 - IoT with Raspberry Pi

1.1 Project Objectives

The main objectives of this project were broken down to three progressive steps:

Week 01

- Initial motive was to familiarize with the Raspberry Pi 3 b module, by creating a documentation.
- Implementing simple tasks like led-blink using the Raspberry Pi module

Week 02

- Environmental Sensing: Develop a system to accurately measure temperature and humidity using the DHT11 sensor and acquire real-time data.
- Automation: Implement automation by controlling the relay, which, in turn, activates an external device (such as an LED) based on specific environmental conditions.
- Data Visualization: Display the collected sensor data, including date, time, temperature, and humidity, on the Raspberry Pi's console to monitor real-time changes.

Week 03

- Enabling remote data access: Send the acquired sensor data, along with the relay state, to a remote Mosquitto MQTT broker to enable data sharing and monitoring.
- Data logging: Create a PostgreSQL database to log the received sensor data and relay status for historical analysis and long-term data storage

The project involved the integration of the DHT11 sensor, relay, and LED with the Raspberry Pi 3 B module. The DHT11 sensor was used to measure ambient temperature and humidity, while the relay provided the capability to control external devices based on humidity or temperature thresholds. The LED served as a simple indicator of the relay status, facilitating visual indication.

To achieve automation, the Raspberry Pi system was programmed to activate the relay and turn on the LED when the humidity level fell within the specified range (e.g., 60% to 70%). Conversely, the relay was deactivated and the LED turned off when the humidity was outside the prescribed range.

The Raspberry Pi's console provided real-time data visualization, displaying the date, time, temperature, and humidity at a regular interval. Additionally, the collected sensor data, including the relay state, was published to a Mosquitto MQTT broker for remote monitoring.

Finally, the MQTT broker data was subscribed and real time data was logged onto PostgreSQL database with the aid of a python code run on the console of a laptop. This allowed the sensor data and relay status to be effectively logged for further analysis, historical records, and potential integration with other applications.

2. Theory and Literature Review

2.1 Documentation on Raspberry Pi

2.1.1 Introduction

Raspberry is mini sized, low-cost and powerful device that is normally plugged into a computer monitor or TV along with a mouse and a keyboard. It almost acts like a normal desktop computer and can be used to emulate many of its functionalities. The device can used by people of any age group from kids to professionals. It was developed by the Raspberry Pi Foundation, a UK based educational charity organization with the motive of familiarizing kids as well as adults in the field of computer, computer science and related subjects. The GPIO pins of the device allows to control electronic components for physical computing and explore the Internet of Things.

Over the years there have been many generations of Raspberry Pi. The below mentioned are various different series of Raspberry Pi.

1. Raspberry Pi
2. Raspberry Pi 2
3. Raspberry Pi Zero
4. Raspberry Pi 3
5. Raspberry Pi 4

6. Raspberry Pi Pico

Type of series	Processor	RAM	I/O ports	Connectivity
Raspberry Pi	Single-core ARM	256-512 MB	USB, HDMI, Ethernet and GPIO	No integrated Wi-Fi or Bluetooth
Raspberry Pi 2	Quad-core ARM Cortex-A7	1GB	USB, HDMI, Ethernet and GPIO	No integrated Wi-Fi or Bluetooth
Raspberry Pi 3	Quad-core ARM Cortex-A53	1 - 1.5GB	USB, HDMI, Ethernet and GPIO	Integrated Wi-Fi and Bluetooth
Raspberry Pi 4	Quad-core ARM Cortex-A72	2 – 8 GB	USB 3.0 ports, dual HDMI outputs, Gigabit Ethernet, and GPIO	Integrated Wi-Fi and Bluetooth
Raspberry Pi Zero	Single-core ARM	512 MB	mini-HDMI, micro-USB, and GPIO	No integrated Wi-Fi or Bluetooth (Raspberry Pi Zero W is an exception)
Raspberry Pi Pico	Dual-core ARM Cortex-M0+	264 kB	GPIO pins, UART, SPI, I2C, and more	No integrated Wi-Fi or Bluetooth

2.1.2 Pin specification and their functions

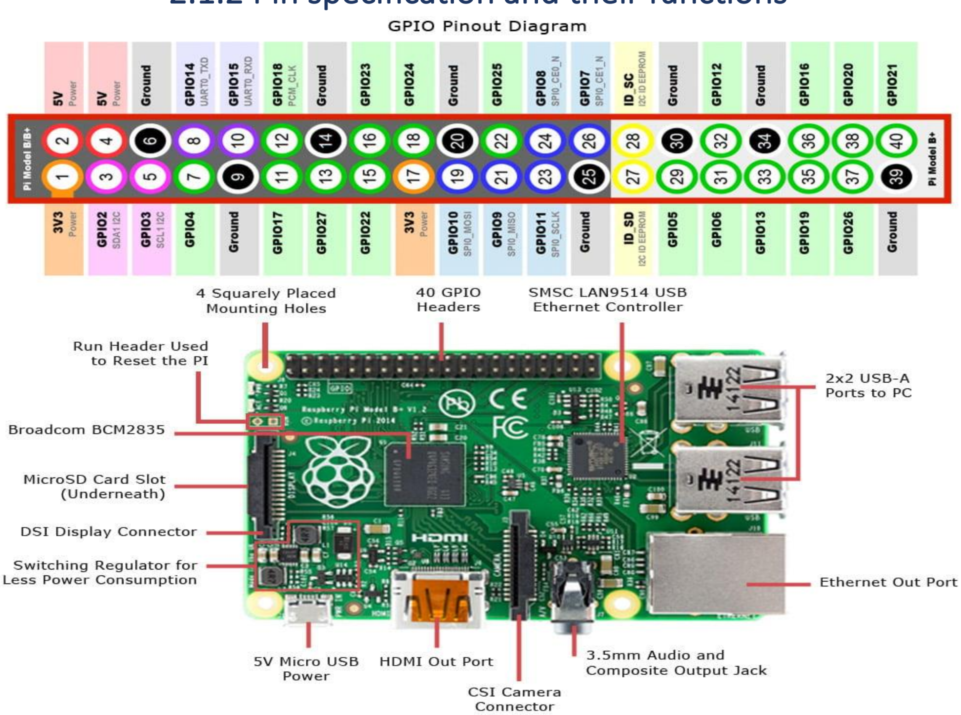

Figure 2 Pinout of Raspberry Pi 3b module

Power pins

Pin number 01 – 3.3V power pin

Pin number 02 – 5V power pin

Ground Pins

Pin numbers 6, 9 , 14 , 20 , 25 , 30 , 34 and 39 – 0V ground pins

*The above-mentioned power and ground pins are unconfigurable

Outputs

A GPIO pin designated as an output pin can be set to high (3.3V) or low (0V).

Inputs

A GPIO pin which is assigned as input can read as high as 3.3V or low as 0V(3.3-1.8V is considered HIGH while 1.8-0V is considered LOW). This specific functionality is made easier with the use of internal pullup and pulldown resistors. (GPIO2 and GPIO3 have fixed pullup resistors, while for others this can be setup using the software)

Other Special features of GPIO pins

Pulse Width Modulation

PWM stands for Pulse Width Modulation. It is a technique used to control the average power delivered to a load by rapidly switching a digital signal on and off. By varying the width of the pulse, the average voltage or power supplied to the load can be adjusted.

- Software PWM available on all pins
- Hardware PWM available on GPIO12, GPIO13, GPIO18, GPIO19

SPI – Serial Peripheral Interface

SPI stands for Serial Peripheral Interface. It is a synchronous serial communication interface that allows the Raspberry Pi to communicate with other devices, such as sensors, displays, and memory chips. SPI is commonly used for short-distance communication between devices on the same circuit board or within a small system.

This specific model of Raspberry Pi has 4 separate connections to communicate with the target device. These connections are the serial clock (CLK), Master Input Slave Output (MISO), Master Output Slave Input (MOSI) and Chip Select (CS). The module has a dedicated SPI interface that supports full-duplex communication, allowing data to be simultaneously transmitted and received.

- MOSI (Master Out Slave In): This line is used for data transmission from the Raspberry Pi (master) to the connected device (slave).
- MISO (Master In Slave Out): This line is used for data transmission from the connected device (slave) to the Raspberry Pi (master).
- SCLK (Serial Clock): This line provides the clock signal that synchronizes the data transfer between the Raspberry Pi and the connected device.

- CE0 (Chip Enable 0): This line is used to select the specific device with which the Raspberry Pi wants to communicate. Multiple devices can be connected to the SPI bus, and each device is selected by setting the corresponding chip enable line.

SPI0: MOSI (GPIO10); MISO (GPIO9); SCLK (GPIO11); CE0 (GPIO8), CE1 (GPIO7)

SPI1: MOSI (GPIO20); MISO (GPIO19); SCLK (GPIO21); CE0 (GPIO18); CE1 (GPIO17); CE2 (GPIO16)

I2C – Inter Integrated Circuit

I2C (Inter Integrated Circuit) is a synchronous serial protocol that communicates data between two devices. It is a master-slave protocol which may have one master or many master and many slaves whereas SPI has only one master. It is generally used for communication over short distance. The I2C device has 7-bit or 10-bit unique address. So, to access these devices, master should address them by the 7-bit or 10-bit unique address. I2C is used in many applications like reading RTC (Real time clock), accessing external EEPROM memory. It is also used in sensor modules like gyro, magnetometer etc.

The Raspberry Pi 3 Model B has dedicated I2C pins that support I2C communication. These pins are as follows:

- SDA1 (Serial Data Line): This is the data line for I2C communication. It carries the actual data being transmitted between the Raspberry Pi and the connected devices.
- SCL1 (Serial Clock Line): This is the clock line for I2C communication. It provides the synchronization signal for the data transfer between the Raspberry Pi and the connected devices.

I2C

- Data: (GPIO2); Clock (GPIO3)
- EEPROM Data: (GPIO0); EEPROM Clock (GPIO1)

UART

Raspberry Pi has two in-built UART which are as follows:

- PL011 UART
- mini UART

PL011 UART is an ARM based UART. This UART has better throughput than mini UART. In Raspberry Pi 3, mini UART is used for Linux console output whereas PL011 is connected to the On-board Bluetooth module.

Mini UART uses the frequency which is linked to the core frequency of GPU. So as the GPU core frequency changes, the frequency of UART will also change which in turn will change the baud rate for UART. This makes the mini UART unstable which may lead to data loss or corruption. To make mini UART stable, fix the core frequency. mini UART doesn't have parity support.

The PL011 is a stable and high performance UART. For better and effective communication use PL011 UART instead of mini UART. It is recommended to enable the UART of Raspberry Pi for serial communication. Otherwise, we are not able to communicate serially as UART ports are used for Linux console output and Bluetooth module.

UART pins of Raspberry Pi 3 b module are.

- UART_TXD0 – GPIO14
- UART_RXD0 – GPIO15

2.1.3 Ways in which Raspberry Pi communicate with external devices

GPIO (General Purpose Input/Output): The module has a set of GPIO pins that can be used for general-purpose digital input and output. These pins can be used to communicate with external devices by sending and receiving digital signals.

Serial Communication: The module supports UART (Universal Asynchronous Receiver-Transmitter) or serial communication. It has dedicated TXD and RXD pins that can be used to establish serial communication with other devices using protocols like RS-232, RS-485, or TTL-level serial.

I2C (Inter-Integrated Circuit): The device has dedicated I2C pins that support the I2C communication protocol. I2C allows for multi-device communication using a master-slave architecture, where multiple devices can be connected to the same bus and controlled by the Raspberry Pi.

SPI (Serial Peripheral Interface): The device supports the SPI communication protocol. It has dedicated SPI pins that allow for full-duplex communication with SPI devices such as sensors, displays, and memory chips.

USB (Universal Serial Bus): The device has USB ports that can be used to communicate with a wide range of USB devices, including keyboards, mice, storage devices, and other peripherals. USB provides a versatile and standardized method of communication.

Ethernet: It also has an Ethernet port that enables communication with other devices over a local network or the internet. It can be used for various networking applications, including file sharing, remote access, and web-based interactions.

Wi-Fi and Bluetooth: Unlike certain other modules, this specific module also have built-in Wi-Fi and Bluetooth capabilities. These wireless technologies allow the Raspberry Pi to communicate with other devices wirelessly, opening up possibilities for IoT (Internet of Things) applications, wireless connectivity, and data exchange.

2.1.4 Diversified usage of Raspberry Pi modules

Replace Your Desktop PC With a Raspberry Pi

The low-cost device can be used as a basic desktop computer for web browsing, document editing, programming, and other day-to-day tasks. Raspberry Pi OS provides a user-friendly desktop environment for such usage.

Print With Your Raspberry Pi

Irrespective of whether you have an old printer that doesn't have wireless, or one that is difficult to connect to network, you can avoid sending it to landfill by employing a Raspberry Pi.

Team up the Samba file sharing software, and CUPS print software, and you can make that printer wireless. The Common Unix Printing System provides drivers for your printer and provides an administration console. Once this is set up, any computer on your home network can access the printer.

Learning and Education

The Raspberry Pi is an excellent tool for learning programming, electronics, and computer science. It provides a platform for experimentation, coding projects, and educational resources. Since Raspberry Pi is also being used in the professional world, having hands on experience with this module would be great.

Act as Game Servers

Raspbian, the default OS of pi comes with a special version of Minecraft game pre-installed. But, the applications of Raspberry Pi can be used as a game server as well. It is an excellent game server for Minecraft. If multiple Raspberry Pis are used, making one as a dedicated server, a great gaming experience can be achieved. Other multiplayer network games can be set up on the Raspberry Pi.

Retro Gaming Machine

As well as streaming media, the Raspberry Pi is ideal as a retro gaming machine. Compact and powerful enough to be used in several ways, the device is suitable as a full-size arcade cabinet, or even as part of a Game Boy-esque handheld.

Various retro gaming operating systems are available, all with controller support. Many classic gaming platforms can be emulated, from MS-DOS and 16-bit consoles to the Commodore 64.

Internet of Things (IoT) Applications

Utilize the Raspberry Pi's networking capabilities to create IoT projects. Connect sensors, actuators, and other devices to the Pi and enable data collection, remote control, and monitoring.

Robot controller

Combine the Raspberry Pi with motors, sensors, and a chassis to build a robot. Program the Raspberry Pi to control the robot's movements, interact with its environment, and perform tasks.

Setup a stop-motion camera

Stop-motion video is becoming increasingly popular as an art form, with uploaders of all ages sharing their movies on YouTube and social media. But how is stop-motion made? You can find out with a Raspberry Pi and a dedicated camera module.

Using the Python programming language, a suitable mount (overhead for Gilliam-esque paper craft animation, a standard tripod for clay- or toy-based), and a well-lit area, you'll also need to rig a button to the Pi's GPIO.

Personal Cloud Server

Transform your Raspberry Pi into a personal cloud server using software like Nextcloud or OwnCloud. You can store and access your files, host websites, manage calendars, and more.

Setting up a time-lapse camera

The Raspberry Pi camera modulandfferent script creates another use that captures movies. This can be achieved by taking single frames with a time delay. Also needed is, perhaps a portable battery solution, and a tripod can be used. A smartphone tripod is most preferred to ensure the device remains sturdy.

Home Automation

Use the Raspberry Pi along with sensors, relays, and actuators to build a home automation system. Control lights, appliances, temperature, and security systems using your Raspberry Pi as the central controller.

FM radio station

Raspberry Pi can also be used to broadcast on FM radio. Pi can broadcast only over a short-range. A portable battery and soldering skills may be required here. Any audio which needs to broadcast will need to be loaded beforehand to the microSD card.

Web servers

Another great application of Raspberry Pi are to create a web server out of it. What this means is that it can be configured to host a website much like any other server. It can host blogs too. First of all, the right software needs to be installed and that is Apache and its dependent libraries. A full LAMP stack can also be installed with PHP, MySQL, and Apache too. Setting up FTP is also helpful.

Once all these steps as mentioned are completed, HTML files can be saved into the /www/ directory, and the webserver is ready to be used. Specific web software like WordPress can also be used once the server setup is complete.

2.2 DHT11 Temperature and Humidity sensor module

DHT11 sensor module is a widely used sensor, it has the ability to measure temperature and humidity in the range of 0 ºC to 50 ºC and 20% to 90% with an accuracy of ±1 C and ±1% respectively.

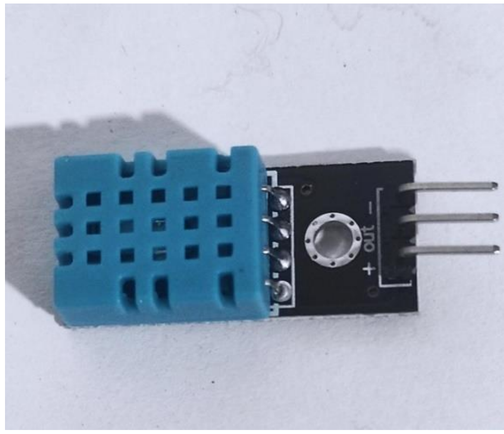

Figure 3 - DHT11 sensor module

Pin	Pin Name	Description
+	VCC	Power input of 3.5-5V
Out	Data	Gives out temperature and humidity readings as serial data
-	Ground	Ground connection of circuit

Table 1- Pinout of DHT11 sensor with brief descriptions of each pin

It should be noted that DHT11 sensor and DHT11 sensor module are slightly different to each other. Sensor module is a 3-pin device with inbuilt capacitor and pullup resistor while, the sensor alone is a 4-pin device where only 3 pins should be used. For the sensor pullup resistors and capacitors should be used externally. Even though there are various advantages of using DHT11 sensor, the fact that its factory calibrated stands out from others. It has customized libraries built to facilitate interfacing with Raspberry Pi and it's very easy to set the circuit up.

2.3 5V relay module

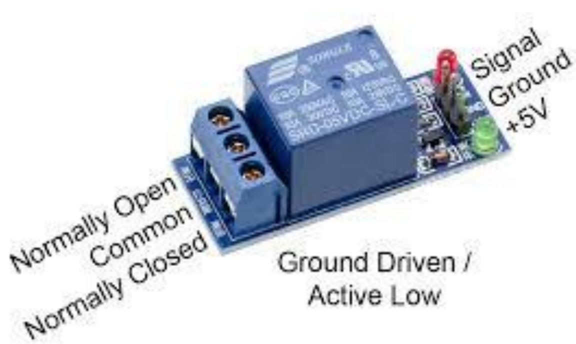

Figure 4 - Pinout of 5V relay module

Relay in brief is a kind of electromechanical switch module capable of controlling high-power electrical devices using a low-power signal. When the relay is energized with a 5V DC input signal, the relay's coil generates a magnetic field that switches the relay contacts, either turning the connected device ON or OFF. A single channel 5V relay module generally includes a coil, and two contacts like normally open (NO) and normally closed (NC). One of the main advantages of relay modules over simple switches is that the relay module with a single channel board can be used to manage high voltage, current loads like solenoid valves, motor, AC load & lamps.

2.4 Mosquitto MQTT broker

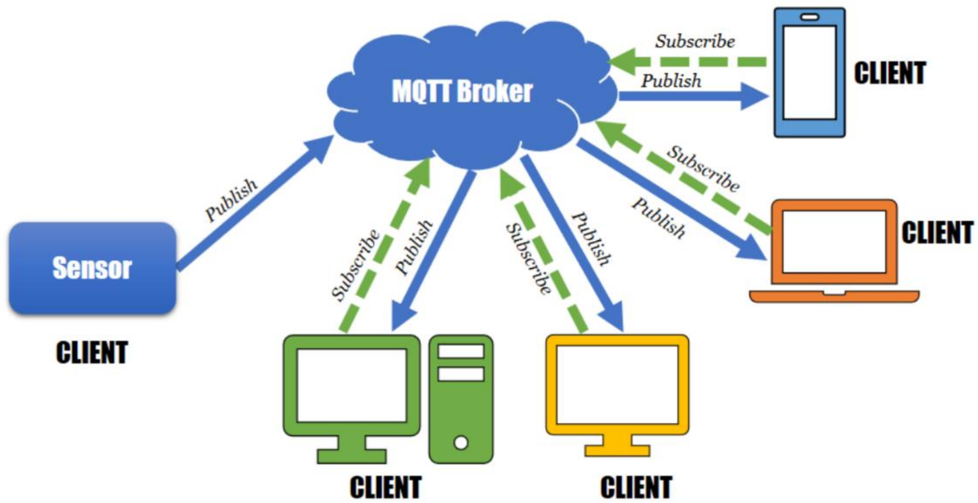

Figure 5 - The diagram shows the working pattern of an MQTT broker

The Mosquitto MQTT broker is an open-source message broker that facilitates communication between connected devices by implementing MQTT protocols in the world of Internet of Things (IoT). Mosquitto is lightweight and is suitable for use on all devices from low power single board computers to full servers. As an MQTT (Message Queuing Telemetry Transport) broker, Mosquitto enables efficient, lightweight, and real-time data exchange over a network. It follows the publish-subscribe messaging pattern, where devices can publish data (messages) to specific topics, and other devices can subscribe to those topics to receive the published data. The broker acts as the central hub, where all the routing of messages to its connected devices takes place. The fact that its simple, low resource consumption and compatible with various platforms makes it suitable for Internet of Things messaging such as with low power sensors or mobile devices such as phones, embedded computers or microcontrollers.

2.5 PostgreSQL

Figure 6 - Depicts the logo of PostgreSQL

PostgreSQL is a powerful open-source relational database management system. It offers a flexible data model, allowing users to define custom data types and create complex data structures. PostgreSQL provides comprehensive support for SQL which includes a wide range of functions and operators for data manipulation and analysis. With its multi-user concurrency control, it can handle concurrent operations from multiple clients without compromising data integrity. PostgreSQL's reliability, scalability, and support for advanced features like JSON data types and full-text search make it a preferred choice for various applications, including web development, data warehousing, and geospatial data management. As a free and open-source solution, PostgreSQL continues to be widely adopted by simplest of developers to top professional bodies.

3. Methodology