SOLAR PANEL DEFECT DETECTION AND MONITORING SYSTEM

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

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ABSTRACT

This article outlines the development of an IoT-based fault detection and monitoring system designed to enhance the reliability and performance of solar photovoltaic panels. The system integrates several sensors to collect real-time data on key parameters such as panel temperature, voltage, light intensity, dust concentration, ambient temperature and humidity. A DS18B20 sensor is used to monitor the surface temperature of the solar panel, DHT22 sensor captures ambient temperature and humidity. Voltage and current readings are obtained through the INA219 sensor, which helps detect electrical anomalies. The BH1750 sensor measures light intensity in lux, enabling the system to detect anomalies like high irradiance with low voltage output, which may indicate solar panel soiling. To measure dust accumulation and its impact, a GP2Y1010AU0F dust sensor is employed, which sends alerts when dust density exceeds a threshold. All sensor data is processed by an ESP32 microcontroller, which displays key information on an LCD and notifies users of significant faults. This real-time monitoring system enables early detection of issues like soiling, overheating, electrical faults, allowing for timely maintenance and reduced downtime. Designed with simplicity, cost-effectiveness, and scalability in mind, the system is suitable for both residential and commercial solar applications. Its modular architecture allows for future enhancements such as cloud integration, predictive maintenance using machine learning, and automated cleaning mechanisms.

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
IoT	Internet of Things
PV	Photovoltaic
ESP32	Espressif Systems 32-bit Microcontroller
LCD	Liquid Crystal Display
DS18B20	Digital Temperature
DHT22	Digital Humidity and Temperature
INA219	Current/Voltage Sensor
BH1750	Digital Light Intensity Sensor
Wi-Fi	Wireless Fidelity
Lux	Unit of Illuminance

CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.1 OVERVIEW

The global demand for renewable energy is steadily increasing as the world seeks sustainable solutions to address environmental degradation and rising energy needs. Among the various renewable sources, solar energy has gained significant attention due to its abundance, eco-friendliness, and decreasing costs of implementation. Solar photovoltaic systems convert sunlight directly into electricity, offering a clean, efficient energy solution for both residential and industrial sectors. It detect the problems such as dust accumulation, excessive heat, humidity, electrical faults can cause performance degradation, resulting in energy loss and increased operational costs.

To address these challenges, it introduces a cost-effective, smart IoT-based fault detection and monitoring system for solar PV panels. The proposed system is designed to monitor real-time parameters that influence solar panel efficiency, including panel temperature, ambient temperature, humidity, voltage, current, light intensity and dust density.

By leveraging the power of the Internet of Things, the system ensures continuous observation, fault detection, instant user notification, allowing for proactive maintenance and optimal energy production. environmental conditions that might impact panel performance. The INA219 sensor is employed to monitor the current and voltage output, Light intensity, a crucial factor for solar panel output, is monitored by the BH1750 sensor, which provides readings in lux. When the system detects high lux levels but low voltage or current output, it can infer a possible fault dust deposition. To directly measure the presence of dust particles, the GP2Y1010AU0F optical dust sensor is used. If dust levels exceed a threshold, the system alerts the user to clean the panel.

All collected sensor data is processed by the ESP32 microcontroller and displayed on an LCD screen for real-time on-site monitoring. Additionally, through IoT-based communication, users receive notifications about abnormal conditions, enabling them to take timely corrective actions. The primary advantage of this system is its ability to detect and report faults automatically, eliminating the need for manual inspection and reducing the risk of energy loss.

1.2 OBJECTIVE

The objective of the project is to enhance the performance and reliability of solar photovoltaic panels by detecting faults such as overheating, dust accumulation, shading, and abnormal voltage drops. The system utilizes an ESP32 microcontroller integrated with various sensors, including DS18B20 for panel temperature, DHT22 for ambient temperature and humidity, INA219 for current and voltage, BH1750 for light intensity, and GP2Y1010AU0F for dust particle concentration.

Challenges faced included sensor calibration, power management for outdoor systems, and precise timing for real-time synchronization. The project demonstrated strong potential for scalability, with future enhancements possible through machine learning integration, predictive maintenance, and automated cleaning systems. Overall, the system offers a cost-effective, reliable solution for improving solar panel efficiency and supports the broader adoption of clean energy technologies.

1.3 PROJECT IMPACT

The implementation of an IoT-based solar panel fault detection and monitoring system has a multifaceted impact on both the technical and practical dimensions of solar energy utilization. This project addresses critical issues that affect the performance and reliability of photovoltaic panels such as soiling, overheating, and electrical anomalies by offering a real-time, intelligent diagnostic approach that enhances operational efficiency.

At its core, the system integrates a variety of sensors with an ESP32 microcontroller and a fuzzy logic algorithm to interpret environmental, electrical parameters with a high degree of accuracy. By automating fault detection, the project reduces the need for manual inspection, saving labor costs and minimizing downtime. The project leverages affordable components like DHT22, INA219, BH1750, DS18B20 and GP2Y1010AU0F dust sensor, making it cost-effective and scalable for various deployment scenarios from individual household solar systems to large-scale solar farms. The system's integration with ThingSpeak enables cloud-based remote monitoring and mobile notifications, promoting ease of access and real-time visibility for end maintenance teams.

CHAPTER 2

LITERATURE SURVEY

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE REVIEW

Title: IoT based Solar Photo Voltaic Fault Detection System.

Year: 2023

Authors: Mridul , Bhuvnesh Vashishat , Anil Kumar, Rohit Kumar

The development of an IoT-based monitoring and fault detection system for solar photovoltaic installations. Leveraging the Internet of Things, the system enables real-time data acquisition, remote control, intelligent decision-making, significantly enhancing the reliability and efficiency of solar energy system [3]. By integrating smart devices such as D-PMUs, Arduino, and Raspberry Pi, the system can detect faults caused by variations in irradiance, temperature, and other environmental factors, it also facilitates remote operation of the power distribution network. This approach not only minimizes manual intervention but also supports the growing shift towards sustainable and decentralized energy solutions.

2.2 EXISTING SYSTEM

Traditional solar panel monitoring systems predominantly rely on basic electrical measurements such as voltage, current, and power output to evaluate panel performance. These systems typically use fixed threshold-based logic, where readings falling outside predefined limits are flagged as faults. While simple to implement, this binary classification method is often ineffective in detecting complex issues like partial shading, dust accumulation, gradual degradation, temperature induced losses and microcracks. Additionally, existing systems often ignore external environmental factors such as ambient temperature, humidity, sunlight intensity, which play a crucial role in panel efficiency. Many traditional setups also lack secondary sensing mechanisms like irradiance sensors or dust detection modules, limiting the diagnostic depth and accuracy.

The conventional systems typically do not support remote monitoring and cloud connectivity, requiring manual inspections that increase maintenance time and operational costs. The lack of smart decision-making capabilities, real-time data processing, and adaptability to changing environmental conditions makes traditional systems outdated for modern solar installations. These limitations emphasize the urgent need for intelligent, IoT-enabled, and context-aware fault detection systems capable of ensuring better efficiency, reliability, and responsiveness in solar PV panel management.

2.3 PROBLEM STATEMENT

The growing adoption of solar photovoltaic systems, maintaining their efficiency and reliability remains a major challenge due to undetected faults such as soiling, shading, overheating, and electrical anomalies. Existing monitoring systems primarily depend on simple voltage and current measurements with fixed thresholds, lacking the ability to intelligently interpret environmental variations and fault conditions. Moreover, traditional systems often do not integrate additional sensing elements for parameters like ambient temperature, light intensity, or dust accumulation, leading to incomplete diagnosis and delayed maintenance responses. It is essential to develop a smart, cost-efficient IoT-based fault detection and monitoring system that enables real-time data acquisition, intelligent analysis through soft computing techniques such as fuzzy logic, and cloud-based remote monitoring. This approach ensures timely maintenance, maximizes energy output, and extends the lifespan of the system.

2.4 PROPOSED SYSTEM

To overcome the limitations of traditional monitoring systems, the proposed solution introduces an IoT-based smart fault detection and monitoring system specifically designed for solar photovoltaic panels. This system integrates a range of environmental and electrical sensors including DS18B20 for panel temperature, DHT22 for ambient temperature and humidity, INA219 for voltage and current, BH1750 for light intensity, and GP2Y1010AU0F for dust accumulation. These sensors feed real-time data to an ESP32 microcontroller, which processes the inputs using a fuzzy logic-based fault detection algorithm. Unlike threshold based approaches, fuzzy logic enables the system to handle imprecise data and detect fault conditions such as high light intensity with low voltage, abnormal temperature variations.

The system provides immediate alerts through a buzzer and displays relevant metrics on an LCD. Additionally, sensor data is transmitted to the cloud via ThingSpeak and displayed on mobile applications like Blynk, enabling remote monitoring and timely maintenance.

CHAPTER 3

SYSTEM SPECIFICATION AND DESIGN

CHAPTER 3

SYSTEM SPECIFICATION AND DESIGN

3.1 INTRODUCTION

The system specification is mainly subdivided into two main divisions:

- Hardware Specification
- Software Specification

3.2 HARDWARE REQUIREMENTS

- Microcontroller -ESP32 WROOM 32
- Light Intensity sensor -BH1750
- Liquid Crystal Display - INA219
- Temperature And Humidity -DHT22
- Voltage and current sensor
- Dust sensor-GP2Y1010AU0F
- Solar panel

3.3 SOFTWARE SPECIFICATION

- Operating System: Windows

3.4DEVELOPMENT SPECIFICATION

- Arduino IDE
- Proteus IDE
- ThingSpeak
- Thingshow

CHAPTER 4

SYSTEM DESIGN

CHAPTER 4
SYSTEM DESIGN

4.1 SYSTEM ARCHITECTURE

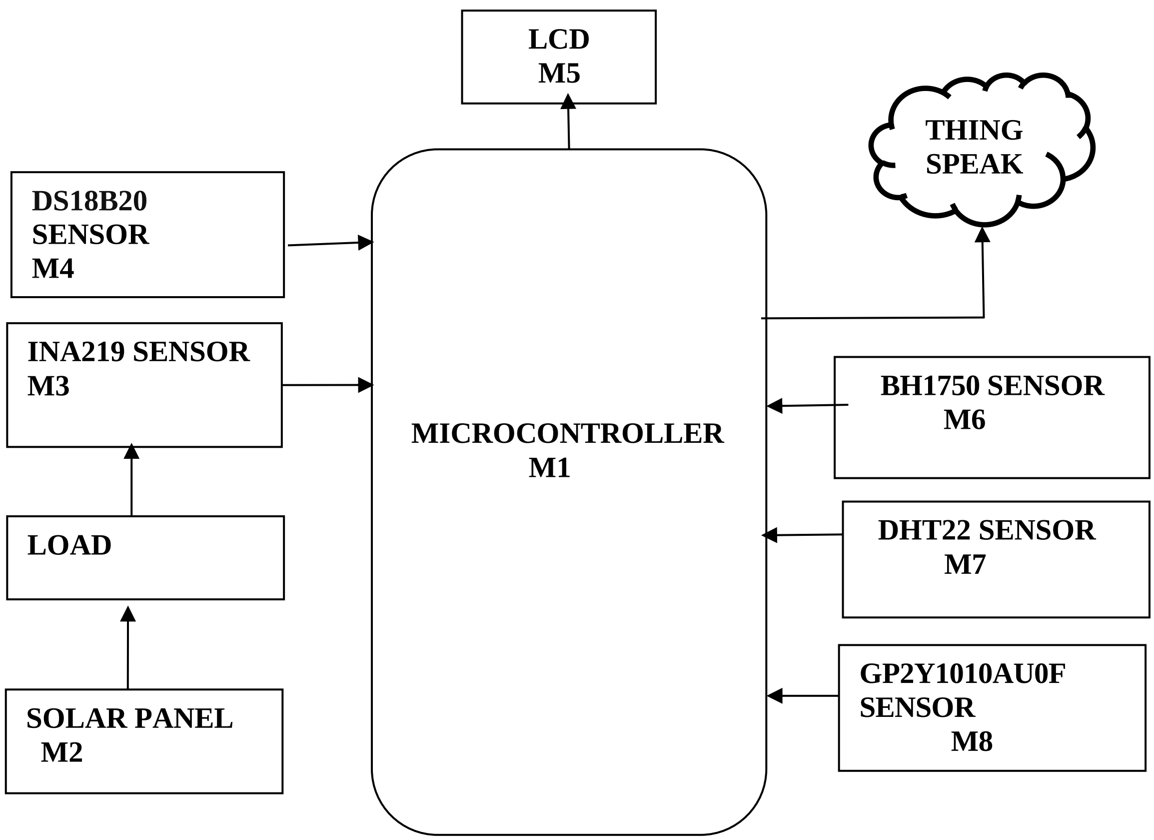

Fig: 4.1.1 BLOCK DIAGRAM

4.2 MODULES

- M1 ESP32 WROOM 32 Microcontroller
- M2 Solar panel
- M3 Voltage and current sensor

- M4 Solar Temperature Sensor
- M3 Liquid Crystal Display
- M5 Light Intensity sensor
- M4 Temperature and Humidity Sensor
- M6 Dust sensor

4.3 OVERALL DESIGN FLOW

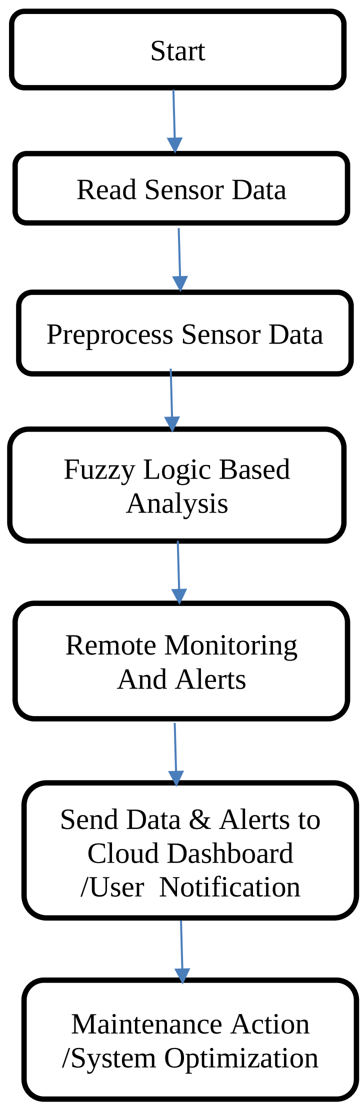

Fig:4.3.1 FLOW CHART

CHAPTER 5

SYSTEM IMPLEMENTATION

CHAPTER 5

SYSTEM IMPLEMENTATION

5.1 HARDWARE COMPONENTS

5.1.1 MODULE 1: ESP32 WROOM 32

The ESP32 is way advanced compared to the ESP-12e. Among several features, the ESP32 packs a CPU core, a faster Wi-Fi, more GPIOs, supports Bluetooth 4.2 and Bluetooth low energy. The board also comes with touch-sensitive pins, alongside a built-in Hall Effect and temperature sensors.

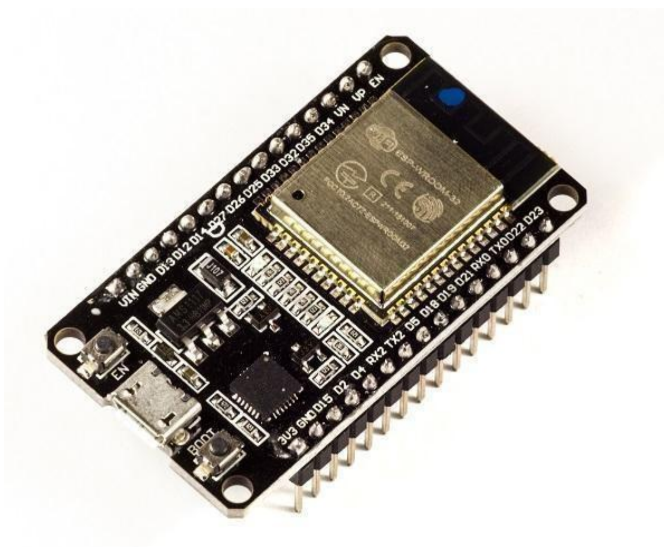

Fig 5.1.1.1 ESP32 WROOM 32

- The specs listed below belong to the ESP32 WROOM 32
- Integrated Crystal− 40 MHz
- Module Interfaces− UART, SPI, I2C, PWM, ADC, DAC, GPIO, pulse counter, capacitive touch sensor
- Integrated SPI flash− 4 MB

- ROM− 448 KB
- SRAM− 520 KB
- Integrated Connectivity Protocols− WiFi, Bluetooth, BLE
- On chip sensor Hall sensor
- Operating temperature range− −40 − 85 degrees Celsius
- Operating Voltage− 3.3V
- Operating Current− 80 mA

The development board equips the ESP-WROOM-32 module containing Tensilica Xtensa® Dual-Core 32-bit LX6 microprocessor. This processor is similar to the ESP8266 but has two CPU cores, operates at 80 to 240 MHz adjustable clock frequency and performs at up to 600 Dhrystone Million Instructions Per Second.

Power Requirements of ESP32 Development Board

The operating voltage range of ESP32 is 2.2V to 3.6V, the board comes with a LDO voltage regulator to keep the voltage steady at 3.3V. It can reliably supply up to 600mA, which should be more than enough when ESP32 pulls as much as 250mA during RF transmissions. The output of the regulator is also broken out to one of the sides of the board and labeled as 3V3. This pin can be used to supply power to external components.

Power to the ESP32 development board is supplied via the on-board Micro USB connector. Alternatively, if you have a regulated 5V voltage source, the VIN pin can be used to directly supply the ESP32 and its peripherals.

The current in the ESP32 chip is less than 5 µA, making it suitable for battery powered and wearable electronics applications.

Peripherals and I/O

The ESP32 has total 48 GPIO pins, only 25 of them are broken out to the pin headers on both sides of the development board. These pins can be assigned to all sorts of peripheral duties, including:

- 15 ADC channels – 15 channels of 12-bit SAR ADC's. The ADC range can be set, in firmware, to either 0-1V, 0-1.4V, 0-2V, or 0-4V.
- UART interfaces – 2 UART interfaces. One is used to load code serially. They feature flow control, and support IrDA too.
- 25 PWM outputs – 25 channels of PWM pins for dimming LEDs or controlling motors.
- DAC channels – 8-bit DACs to produce true analog voltages.
- SPI, I2C & I2S interface – There are 3 SPI and 1 I2C interfaces to hook up all sorts of sensors and peripherals, plus two I2S interfaces if you want to add sound to your project.
- 9 Touch Pads – 9 GPIOs feature capacitive touch sensing.

The ESP32's pin multiplexing feature Multiple peripherals multiplexed on a single GPIO pin. Meaning a single GPIO pin can act as an ADC input/DAC output/Touch pad.

Pin D34, D35, VP and VN cannot be configured as outputs, but they can be used as either digital inputs, analog inputs, or for other unique purposes. Also note that they do not have internal pull-up or pull-down resistors, like the other GPIO pins. GPIO pins VP and VN are an integral part of the ultra-low-noise pre-amplifier for the ADC, which help to configure the sampling time and noise of the pre-amp.

Serial Communication:

Silicon labs which converts USB signal to serial and allows your computer to program and communicate with the ESP32 chip. The board includes CP2102 USB-to-UART Bridge Controller from ESP32 development board.

ESP32 Development Board Pin-out:

The ESP32 development board has total 30 pins that interface it to the outside world. The connections are as follows:

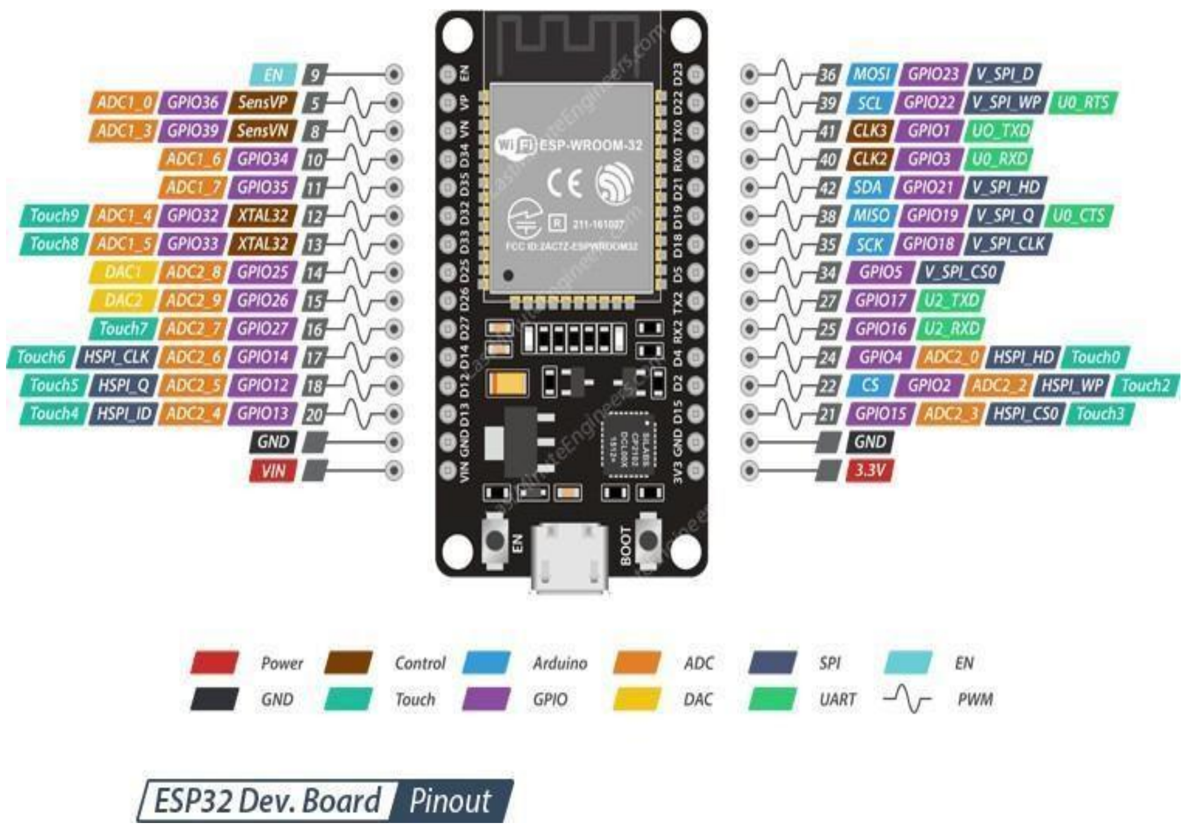

Fig 5.1.1.2 ESP32 DEVELOPMENT BOARD PIN-OUT

Power Pins There are two power pins viz. VIN pin & 3.3V pin. The VIN pin can be used to directly supply the ESP32 and its peripherals, if you have a regulated 5V voltage source. The 3.3V pin is the output of an on-board voltage regulator. This pin can be used to supply power to external components.

GND is a ground pin of ESP32 development board.

Arduino Pins are nothing but ESP32’s hardware I2C and SPI pins to hook up all sorts of sensors and peripherals in your project.

GPIO Pins ESP32 development board has 25 GPIO pins which can be assigned to various functions programmatically. Each digital enabled GPIO can be configured to internal pull-up or pull-down, or set to high impedance. When configured as an input, it can also be set to edge-trigger or level-trigger to generate CPU interrupts.

ADC Channels The board integrates 12-bit SAR ADCs and supports measurements on15 channels analog enabled pins. Some of these pins can be used to build a programmable gain amplifier which is used for the measurement of small analog signals. The ESP32 is also designed to measure the voltages while operating in the sleep mode.

DAC Channels The board features two 8-bit DAC channels to convert digital signals into true analog voltages. This dual DAC can drive other circuits. Touch Pads The board offers 9 capacitive sensing GPIOs which detect capacitive variations introduced by the GPIO’s direct contact or close proximity with a finger or other objects.

UART Pins ESP32 development board has 2 UART interfaces, i.e. UART0 and UART2, which provide asynchronous communication RS232 and RS485 and IrDA support, and communicate at up to 5 Mbps. UART provides hardware management of the CTS and RTS signals and software flow control XON and XOFF as well.

SPI Pins SPI Pins ESP32 features three SPIs SPI, HSPI and VSPI in slave and master modes.

These SPIs also support the following general-purpose SPI features:

- timing modes of the SPI format transfer
- Up to 80 MHz and the divided clocks of 80 MHz
- Up to 64-Byte FIFO

PWM Pins The board has 25 channels of PWM pins controlled by Pulse Width Modulation PWM controller. The PWM output can be used for driving digital motors and LEDs. The controller consists of PWM timers and the PWM operator. Each timer provides timing in synchronous or independent form, and each PWM operator generates the waveform for one PWM channel.

EN Pin is used to enable ESP32. The chip is enabled when pulled HIGH. When pulled LOW the chip works at minimum power.

5.1.2 MODULE 2-SOLAR PANEL

A solar panel, or photo-voltaic PV module, is an assembly of photo-voltaic cells. Solar panels use sunlight as a source of energy and generate direct current electricity A collection of PV modules is called a PV panel, and a system of panels is an array. Arrays of a photovoltaic system supply solar electricity to electrical equipment. 12V 10Watt Solar Panel is engineered with high-efficiency polycrystalline silicon solar cells.

The 10W 12Volts 36-cell Solar Panel is ready to use without requiring a frame or special modifications. The 12v 10W mini Solar Panel has Polycrystalline solar cells which are encased and protected by a durable outer poly frame.

This 3v 150mA mini Solar Panel for DIY Projects is light weighted, very strong and weather-resistant substrates or injection molded trays custom-designed for the target product.

Fig 5.1.2.1 SOLAR PANEL

These Small Epoxy Solar Panels are simple to install or add to your existing product and their construction requires no frame or special modifications. Polycrystalline solar cells have 2 to 3 times the power of amorphous thin-film solar panels. Very small space is required for installation and to connect 12v Solar Panel, just solder or crimp to the copper tape.

Features:

- Best in Class conversion efficiency
- Anti-reflective coating for more light absorption
- Optically, mechanically and electrically tested

Specifications:

- Voltage Rating: 12V
- Max Power Rating: 5 Watt
- Open Circuit Voltage: 22.2V

- Short Circuit Current: 0.29A
- Voltage At Maximum Power: 18.54V
- Current At Maximum Power: 0.27A

5.1.3 MODULE 3- BH1750 – AMBIENT LIGHT SENSOR

In BH1750 is a digital ambient light sensor that is used commonly used in mobile phones to manipulate the screen brightness based on the environment lighting. This sensor can accurately measure the LUX value of light up to 65535lx.

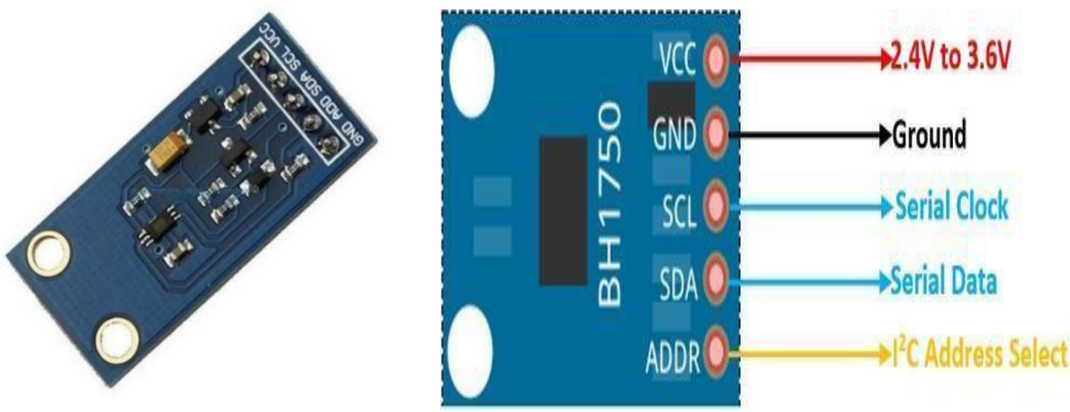

Fig 5.1.3.1: BH1750 – AMBIENT LIGHT SENSOR

BH1750 Features

- Power Supply: 2.4V-3.6V
- Less current consumption: 0.12mA
- Measuring Rang: 1-65535lx
- Communication: I2C bus
- Accuracy: +/-20%

Built in A/D converter for converting analog illuminance in the digital data.

Highly responsive near to human eye

The BH1750 is a light intensity sensor that can be used to adjust the brightness of display in mobiles and LCD displays. It can also be used to turn the headlights of cars on/off based on the outdoor lighting. The sensor uses I2C communication protocol so that makes it super easy to use with microcontrollers. The SCL and SDA pins are for I2C. There is no calculation needed to measure the LUX value because the sensor directly gives the lux value. Actually, it measures the intensity according to the amount of light hitting on it. It operates on voltage range of 2.4V-3.6V and consumes really small current of 0.12mA.

BH1750 pin diagram

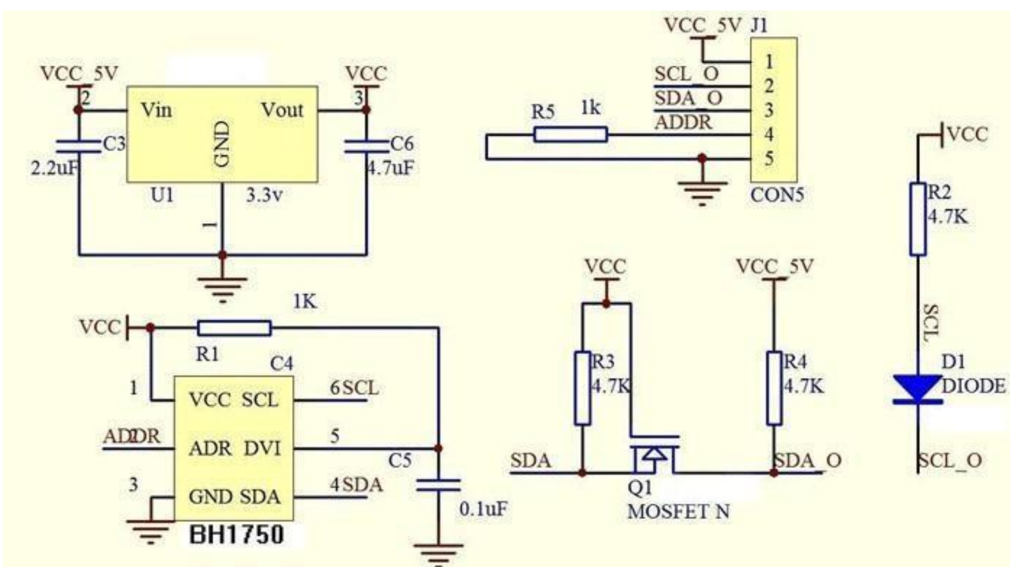

Fig 5.1.3.2 BH1750 pin diagram

Hardware of the BH1750 is very simple. The main component is BH1750FVI IC. The module works on 3.3V so a voltage regulator is used. The lux values from BH1750 through I2C bus. The ADC in the IC converts the analog illuminance to the digital lux value. Now this data is transferred to microcontroller with the help of I2C pins SCL and SDA. The SCL is used to provide the clock pulse and the SDA is used to transfer the lux value. The IC uses a photodiode which gives the response equivalent to the human eye. There is also an internal oscillator in the IC which is used for the clock of internal logic of the IC.

Applications

- Manipulate brightness in mobile phones and LCD
- Automobile Headlights on/off control based on surrounding lighting conditions.
- Used as Ambient light sensors to control the brightness of Display screens.

5.1.4 MODULE 4 DHT22 – TEMPERATURE AND HUMIDITY

The DHT22, also known as AM2302, is a widely used digital sensor for measuring temperature and relative humidity in embedded and IoT applications. It features a dedicated NTC Negative Temperature Coefficient thermistor for accurate temperature sensing and a capacitive humidity sensor to detect moisture levels in the surrounding air. These sensing elements are connected to an onboard 8-bit microcontroller, which processes the analog signals from the sensors and converts them into digital output. The DHT22 is a low-cost, highly accurate digital sensor used to measure both temperature and humidity. It can measure temperatures ranging from -40°C to +80°C with an accuracy of ±0.5°C, and humidity levels from 0% to 100% with an accuracy of ±2–5%. The sensor uses a capacitive humidity sensor and a thermistor to sense the environment, and it outputs a calibrated digital signal via a single data pin, making it easy to interface with microcontrollers like

Arduino and ESP32. Known for its stability and long-term reliability.

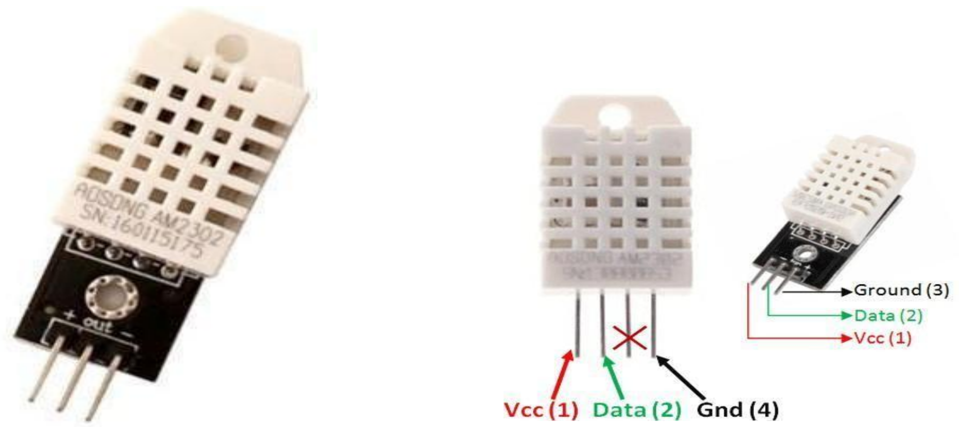

Fig 5.1.4.1 DHT22 – TEMPERATURE AND HUMIDITY SENSOR

Pin Identification and Configuration

No	Pin Nam	Description
1	Vcc	Power supply 3.5V to 5.5V
2	Data	Outputs both Temperature and Humidity through serial Data
3	NC	No Connection and hence not used
4	Ground	Connected to the ground of the circuit

DHT22 Specifications

- Operating Voltage: 3.5V to 5.5V
- Operating current: 0.3mA

- Output: Serial data
- Temperature Range: -40°C to 80°C
- Humidity Range: 0% to 100%
- Accuracy: ±0.5°C and ±1%

The DHT22 is a commonly used Temperature and humidity sensor. The sensor comes with a dedicated NTC to measure temperature and an 8-bit microcontroller to output the values of temperature and humidity as serial data.

The sensor can measure temperature from -40°C to 80°C and humidity from 0% to 100% with an accuracy of ±1°C and ±1%. So if you are looking to measure in this range then this sensor might be the right choice for you.

The DHT22 Sensor is factory calibrated and outputs serial data and hence it is highly easy to set it up. The connection diagram for this sensor is shown below.

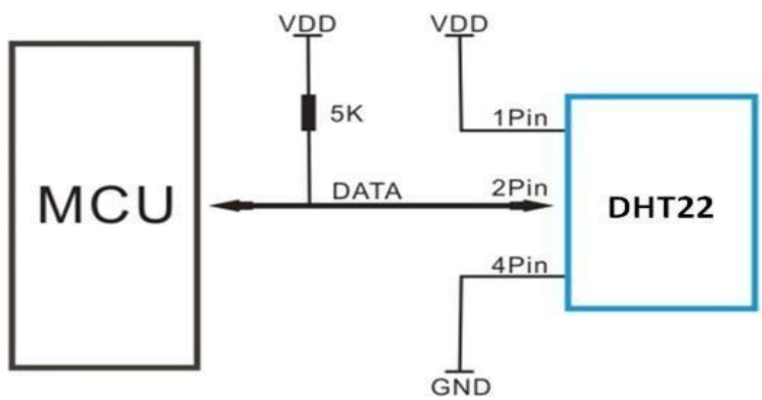

Fig 5.1.4.2 PIN DIAGRAM OF DHT22 –TEMPERATURE AND HUMIDITY SENSOR

The data pin is connected to an I/O pin of the MCU and a 5k pull up resistor is used. This data pin outputs the value of both temperature and humidity as serial data. To interface DHT22 with Arduino Uno then there are ready made libraries for it which will give a quick start.

To interface it with some other MCU then the datasheet given below will come in handy. The output given out by the data pin will be in the order of 8bit humidity integer data + 8bit the Humidity decimal data +8bit temperature integer data + 8bit fractional temperature data +8 bit parity bit.

To request the DHT11 module to send these data the I/O pin has to be momentarily made low and then held high .

Applications

- Measure temperature and humidity
- Local Weather station
- Automatic climate control
- Environment monitoring

5.1.5 MODULE 5 –INA219 -VOLTAGE AND CURRENT SENSOR

The INA219 based Current sensor module CJMCU-219 is an I2C interface based zero drift and bi-directional current/power monitoring module. It can sense shunt voltage, current, and power at the same time and submit the data via I2C protocol. It has 0.1 Ohms, a 1% shunt resistor to fulfill the requirement of current measurements.

current measurement, the module is capable of measuring direct current DC voltage levels up to +26 volts. This wide voltage range makes it suitable for monitoring power systems, including battery packs, solar panels, and various electronic devices. The combination of accurate current and voltage sensing enables the module to compute power consumption and generation.

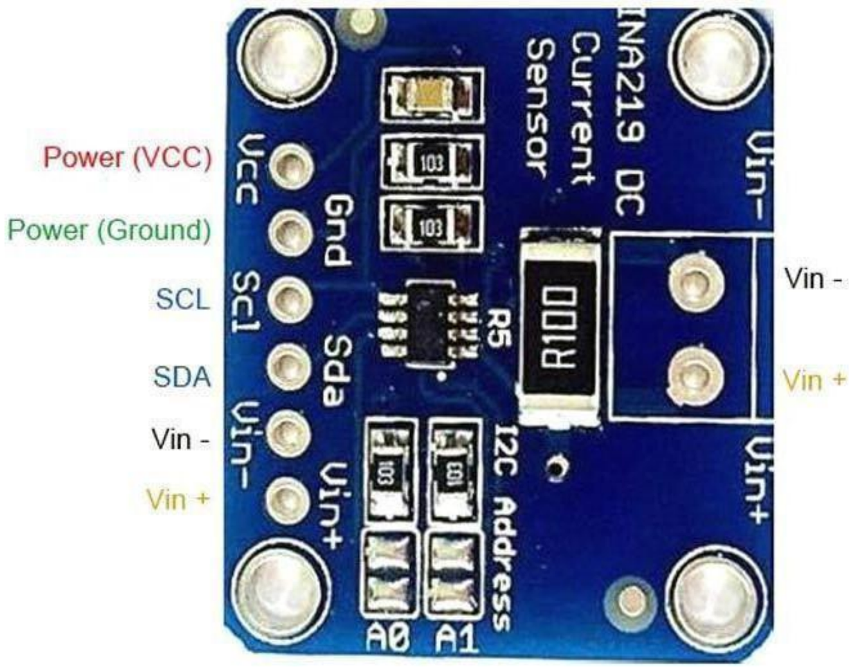

Fig 5.1.5.1. VOLTAGE AND CURRENT SENSOR

INA219 Current Sensor Module Pinout Configuration

Pin Name	Function	Comments
VIN-	Sensed Input line -	Same connection available on the interface section.
VIN+	Sensed Input line +	Same connection available on the interface section.
VCC	Input voltage	For powering up the module

Features

1. Power Input: 3.0V-5.5V

1. Up to +26V target voltage
2. ohm 1% 2W current sense resistor
3. Up to ±3.2A current measurement, with ±0.8mA resolution
4. Senses Bus Voltages from 0 to 26 V

5. 2C- or SMBus-compatible interface
6. The current sensor is an essential component of the power monitoring system.

INA219 is capable of sensing power, voltage, and current with a 128 sample averaging and submitting the data to a host microcontroller using the I2C bus protocol.

The module supports two I2C bus addresses that can be configured using a solderable jumper setting.It has a 2W 0.1 Ohms 1% rated shunt resistor that can be replaced by the desired value. The input section also has a footprint of a terminal block that can be soldered additionally.

5.2 SOFTWARE TOOLS

5.2.1 ARDUINO IDE

Arduino IDE is widely used for programming boards like the ESP32, and it greatly simplifies Embedded C programming for microcontrollers. Arduino is an open-source platform offering easy-to-use hardware and software, making it highly accessible for both beginners and professionals. The Arduino IDE provides a user-friendly environment where programs are written in a simplified version of C++, which closely resembles Embedded C, especially when dealing with low-level hardware control.

Programs can be uploaded directly to microcontroller boards like the ESP32 through a standard USB connection, eliminating the need for separate external programmers or debuggers .The ESP32 using the Arduino IDE, certain setup steps must be followed. First, the ESP32 board package must be added to the Arduino IDE. This involves going to File, Preferences and entering the ESP32 Board Manager URL.

After this step, you need to open the Boards Manager under Tools, Board, Boards Manager, search for ESP32, and install the "ESP32 by Espressif Systems" package. Once installed, users can easily select the specific ESP32 board they are using such as DOIT ESP32 DEVKIT V1 and the correct COM port to establish communication between the board and the computer.

Coding for ESP32 in Arduino IDE follows an Embedded C structure. Developers directly program the microcontroller to control hardware features such as digital input output pins, PWM signals, UART, SPI, I2C communications, analog sensors, and Wi-Fi/Bluetooth modules. The coding style encourages writing structured, efficient, and hardware-optimized programs, typical of Embedded C practices. Arduino libraries simplify complex functions like Wi-Fi connectivity, sensor data processing, and cloud communication, allowing developers to focus on application logic while still maintaining control over hardware interactions.

5.2.2 EMBEDDED C

Embedded C is an extension of the standard C programming language, designed specifically for developing software in embedded systems. An embedded system refers to a specialized computing system that is part of a larger device is designed to perform specific tasks, often with limited computing resources such as memory and processing power.

Unlike general-purpose computing systems that can run a variety of applications, embedded systems are highly task-specific and optimized for real-time performance.

The C programming language has long been the foundation for many software applications due to its efficiency, versatility, and portability. Embedded C takes these core advantages of C and adapts them for environments where hardware interaction and limited resources are crucial factors. While the syntax and structure of Embedded C are similar to that of regular C.

it includes additional features that cater to the unique requirements of embedded systems, such as handling hardware-specific operations, controlling low-level device functions, and managing memory constraints.

One of the significant differences between C and Embedded C lies in the hardware dependency of Embedded C. In traditional C programming, the code is designed to run on general-purpose computing devices with abundant resources.

In embedded systems, the application must work within strict limitations of memory RAM, storage ROM, and processing power, often with real-time constraints.

Embedded C helps developers efficiently program microcontrollers and microprocessors to interact with the hardware directly and perform operations like reading sensors, controlling motors, or handling communication protocols.

Characteristics of Embedded C

1. **Dedicated Software-Hardware Integration:**

Embedded systems are software applications that are tightly integrated with computer hardware. These systems are purpose-built to perform specific functions within larger devices, ensuring that the system can efficiently handle tasks tailored to its application.

2. **Real-Time Output:**

Embedded systems are designed for real-time performance, meaning they provide immediate or timely output in response to input signals. This is critical for applications that require precise and predictable actions, such as automotive control systems, medical devices, and industrial machinery.

3. **Smaller Specialized Components:**

In many cases, embedded systems are a smaller component within a larger device, designed to perform specific functions. These smaller systems interact with both hardware and software to ensure the device performs optimally. For example, the embedded control system in a microwave is responsible for managing cooking times and power settings.

4. **High Reliability and Real-Time Computation**:

One of the hallmarks of embedded systems is their high reliability and the ability to perform real-time computations. They must operate with minimal failure, as they are often critical to the overall operation of larger devices, like in medical equipment or aerospace systems.

5.2.3 PROTEUS

The circuit simulation has been a non-interactive affair. In the early days, net lists were prepared by hand, and output consisted of reams of numbers. If you were lucky, you got a pseudo-graphical output plotted with asterisks to show the voltage and current waveforms.

More recently, schematic capture and on screen graphing have become the norm, but the simulation process is still non-interactive - you draw the circuit, press go, and then study the results in some kind of post processor. This is fine if the circuit you are testing is essentially static in its behavior e.g an oscillator which sits there and oscillates nicely at 1Mhz.

When designing systems that involve physical interaction, such as data entry through a keypad, the simulation environment can become impractical for certain scenarios, necessitating the creation of a physical prototype. This limits the advantages of virtual development, which otherwise significantly boosts design productivity.

Only in educational circles has an attempt been made to present circuit simulation like real life electronics where it is possible to interact with the circuit whilst it is being simulated. The problem here has been that the animated component models have been hard coded into the program.

In addition, the quality of circuit simulation has often left much to be desired. For example, one major product of this type has no timing information within its digital models.

PROTEUS VSM brings you the best of both worlds. It combines a superb mixed mode circuit simulator based on the industry standard SPICE3F5 with animated component models. And it provides an architecture in which additional animated models may be created by anyone, including end users. Indeed, many types of animated model can be produced without resort to coding. Consequently PROTEUS VSM allows professional engineers to run interactive simulations of real designs, and to reap the rewards of this approach to circuit simulation.

And then, if that were not enough, we have created a range of simulator models for popular micro-controllers and a set of animated models for related peripheral devices such as LED and LCD displays, keypads, an RS232 terminal and more. Suddenly it is possible to simulate complete micro-controller systems and thus to develop the software for them without access to a physical prototype. In a world where time to market is becoming more and more important this is a real advantage.

It is also worth pointing out that the processing power of the modern PC is truly awesome. A 300MHz Pentium II PC can simulate simple micro-controller designs in real time, or even faster in some cases

5.2.THINGSPEAK

ThingSpeak is an IoT analytics platform service that allows you to aggregate, visualize and analyze live data streams in the cloud. ThingSpeak provides instant visualizations of data posted by your devices to ThingSpeak. With the ability to execute MATLAB code in ThingSpeak you can perform online analysis and processing of the data as it comes in. ThingSpeak is often used for prototyping and proof of concept IoT systems that require analytics.

Internet of Things describes an emerging trend where a large number of embedded devices are connected to the Internet. These connected devices communicate with people and other things and often provide sensor data to cloud storage and cloud computing resources where the data is processed and analyzed to gain important insights.

IoT solutions are built for many vertical applications such as environmental monitoring and control, health monitoring, vehicle fleet monitoring, industrial monitoring and control, and home automation.

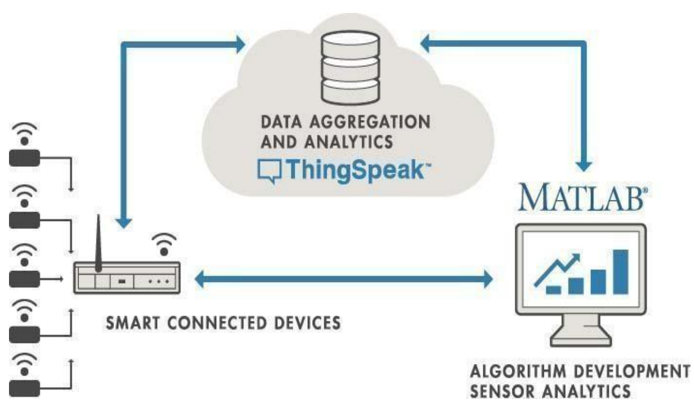

fig 5.2.4.1 IoT SYSTEM

From the above Fig 5.2.4.1 the smart devices that live at the edge of the network. These devices collect data and include things like wearable devices, wireless temperatures sensors, heart rate monitors, and hydraulic pressure sensors, and machines on the factory floor.

the cloud where data from many sources is aggregated and analyzed in real time, often by an IoT analytics platform designed.

The diagram depicts the algorithm development associated with the IoT application. Here an engineer or data scientist tries to gain insight into the collected data by performing historical analysis on the data. In this case, the data is pulled from the IoT platforminto a desktop software.

CHAPTER 6

INTERFACING OF ALL MODULES

CHAPTER 6

INTERFACING OF ALL MODULES

6.1 SYSTEM INTEGRATION

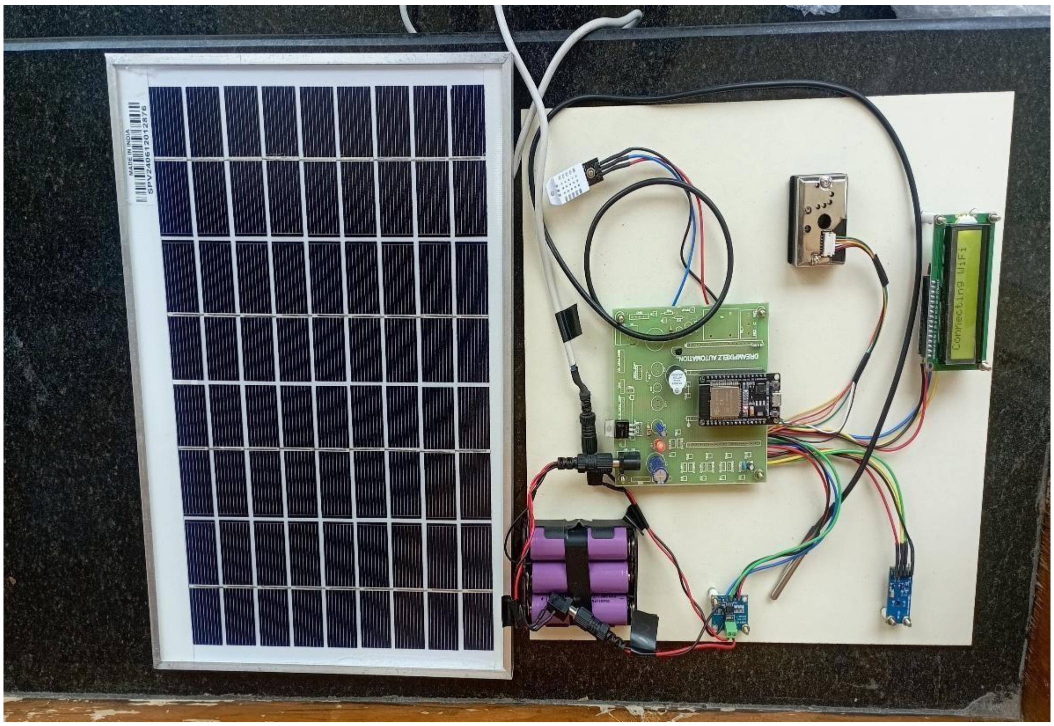

FIG 6.1.1 FINAL MODEL

The above fig 6.1.1 determines the integration of various electronic modules with a solar panel enables the development of a smart solar monitoring system. The setup includes a solar panel for energy generation, an ESP32 microcontroller for processing, and multiple sensors such as voltage, current, temperature, and humidity sensors to monitor the panel's performance. The LCD display provides real-time data, while the system also transmits the collected information to an IoT platform like ThingSpeak for remote monitoring. This integrated approach allows for efficient defect detection, identifying issues such as dust accumulation, cracks, or burns in the panel. The system operates using stored battery power when sunlight is insufficient, ensuring continuous functionality. The main advantages of this project include reduced manual inspection, improved maintenance efficiency, and cost-effectiveness. It is highly applicable in residential solar installations, rural electrification projects, smart grids, and educational research. fig 6.1.1 demonstrates a neatly arranged and fully functional prototype that successfully interfaces all components for effective solar panel monitoring.

6.2 APPLICATION

- **Residential Solar Systems:** Helps homeowners monitor and maintain solar panel health and efficiency.
- **Commercial Solar Installations:** Supports largescale solar centralized monitoring and early fault detection.
- **Remote Solar Installations:** Enables monitoring of solar panels installed in remote or hard-to-reach locations.
- **Research and Development:** Useful for academic institutions and research centers studying solar panel behavior and performance improvements.
- **Smart Cities and Green Buildings:** Contributes to smarter energy management and sustainability initiatives.

CHAPTER 7

CONCLUSION AND FUTURE ENHANCEMENT

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CONCLUSION AND FUTURE ENHANCEMENT

7.1 CONCLUSION

The solar panel defect detection system, implemented using the ESP32 microcontroller and ThingSpeak, has successfully demonstrated its capability to monitor key parameters such as voltage, current, temperature, humidity, dust levels, and light intensity. The system offers real-time monitoring, accurate fault detection, remote alerts, ensuring that solar panel performance is maintained at optimal levels. With a detection accuracy of over 97%, this system can efficiently identify defects such as cracks, dust accumulation, and other performance-impacting issues, significantly reducing downtime and maintenance costs for solar panel installations.

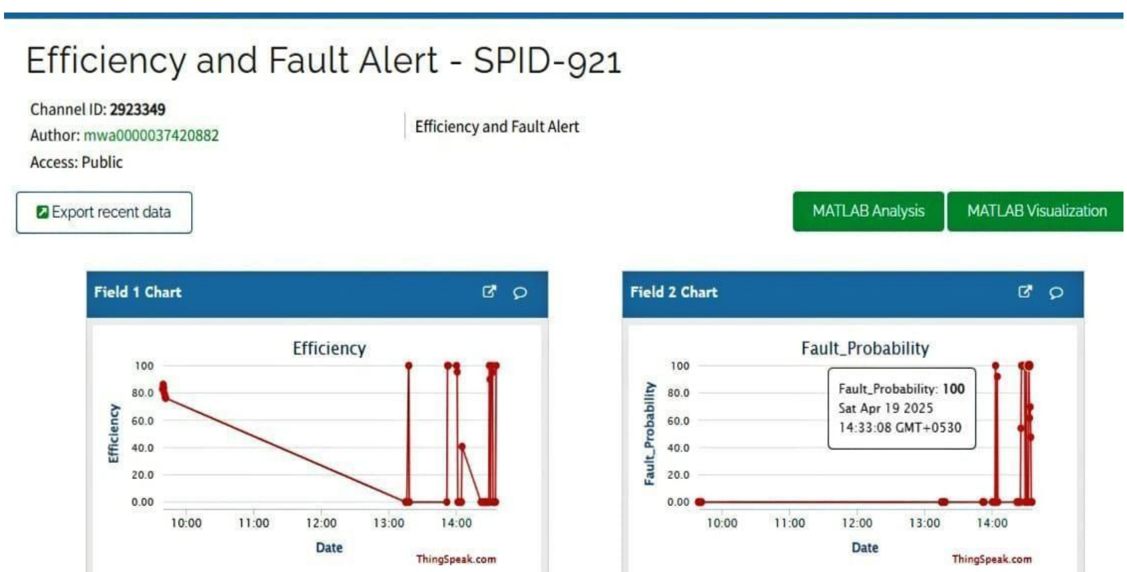

FIG 7.1.1 EFFICIENCY AND FAULT ALERT

The integration of real-time cloud-based data visualization using ThingSpeak has proven to be an effective solution for monitoring solar panel health remotely, providing immediate alerts and allowing for timely intervention. This prototype showcases the potential of low-cost, scalable solutions in enhancing solar panel maintenance and energy production efficiency.

7.2 FUTURE ENHANCEMENT

In future iterations, the system can be enhanced by integrating an automatic cleaning mechanism for the solar panels. A wiper system will be incorporated, which will automatically clean the panels when dust accumulation is detected. The dust level sensor will trigger the wiper to move across the panel and remove any accumulated dust, ensuring that the solar panels continue to operate at peak efficiency.

This enhancement will further improve the system by:

Reducing Manual Intervention: The automatic cleaning feature will minimize the need for manual cleaning, especially in remote locations.

Increasing Panel Efficiency: Regular cleaning of dust will prevent energy loss caused by reduced light absorption, thus increasing overall solar power generation.

Enhancing System Autonomy: The combination of automatic cleaning and fault detection will create a self-sustaining system with minimal human involvement, making it ideal for large-scale or remote solar installations.

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SOURCE CODE

```
#include
<WiFi.h>
#include
<HTTPClient.h>
#include
<LiquidCrystal_I2C.h
> #include
<OneWire.h>
#include
<DallasTemperature.h>
#include "DHT.h"
#include
<GP2Y1010AU0F.h>
#include <Wire.h>
#include <BH1750.h>
#include
<Adafruit_INA219.h
> const char* ssid =
"iot";
const char* password = "qwertyuiop!";
const char* tsServer =
"http://api.thingspeak.com"; const char*
key1 = "Q4OY5UQY8KF9TGKI"; const
char* key2 = "983AF7004DIL4NQN";
DHT dht(19, DHT22);
```

```
OneWire oneWire(15);
DallasTemperature
sensors(&oneWire); BH1750
lightMeter;
Adafruit_INA219 ina219;
GP2Y1010AU0F
dustSensor(12, 33);
LiquidCrystal_I2C
lcd(0x27, 16, 2); int buz = 4,
tv, hv, stv, lv;
String fault_message = "System
Normal"; unsigned long lastTime =
0;
float mf(float x, float a, float b, float c = -1) {
if (c == -1) return x <= a ? 1 : x >= b ? 0 : (b - x) /
(b - a); if (x <= a || x >= c) return 0;
if (x <= b) return (x - a) / (b - a);
return (c - x) / (c - b);
}
void setup() {
Serial.begin(960
0);
pinMode(buz,
OUTPUT);
dht.begin();
sensors.begin();
```

```
dustSensor.begin(); Wire.begin(); lightMeter.begin();
ina219.begin(); lcd.init(); lcd.backlight(); WiFi.begin(ssid,
password);
while (WiFi.status() != WL_CONNECTED) delay(500);
}
void loop() {
readSensors(); fuzzyLogic();
if (millis() - lastTime > 20000) {
if (tv > -40 && tv < 126 && hv > 20 && hv < 81)
sendToThingSpeak(); lastTime = millis();
}
void readSensors() {
hv = dht.readHumidity(); tv = dht.readTemperature();
sensors.requestTemperatures(); stv =
sensors.getTempCByIndex(0);
dv = max(20, dustSensor.read() / 10.0); lv =
lightMeter.readLightLevel(); iv = ina219.getCurrent_mA();
if (iv > 100) {
vv = ina219.getBusVoltage_V(); pv = ina219.getPower_mW() /
1000.0; pv = constrain(pv, 0, 5);
} else vv = iv =
pv = 0;
calcEfficiency();
}
void calcEfficiency() {
float irradiance = lv / 100.0, area = 0.053;
```

```
float maxPower = constrain(irradiance * area, 0,
5); efficiency = maxPower > 0 ? (pv / maxPower)
* 100.0 : 0; if (stv > 45) efficiency *= 0.95;
if (dv > 150) efficiency
*= 0.90; if (hv > 80)
efficiency *= 0.98;
}
void fuzzyLogic() {
float r1 = min(mf(stv, 45, 65), mf(pv, 1, 3));
float r2 = min(mf(dv, 150, 250), mf(pv, 1, 3));
float r3 = min(mf(stv, 25, 45, 65), mf(dv, 50, 150, 250));
float r4 = min(mf(lv, 10000, 20000), mf(pv, 0.5,
1.0)); fault_probability = max(max(r1, max(r2,
r3)), r4) * 100;
if (r4 > 0.7) { fault_message = "DUST ACCUMULATION!";
buzz(2, 200); } else if (fault_probability >
  70){fault_message = "CRITICAL
FAULT!"; digitalWrite(buz, HIGH); }
else if (fault_probability > 40) { fault_message = "Warning"; buzz(1, 500); }
else { fault_message = "System Normal"; digitalWrite(buz,
LOW); } lcd.clear(); lcd.setCursor(0, 0);
lcd.print("Fault:"); lcd.print(fault_probability, 0); lcd.print("%");
lcd.setCursor(0, 1); lcd.print(fault_message);
delay(2000);
}
void buzz(int times, int
delayTime) { for (int i = 0; i
```

```
< times; i++) {
digitalWrite(buz, HIGH);
delay(delayTime); digital Write(buz,
LOW); delay(delayTime);
}
void sendToThingSpeak() {
if (WiFi.status() == WL_CONNECTED)
{ HTTPClient http;
String url1 = String(tsServer) + "/update?api_key=" + key1 +
"&field1=" + tv + "&field2=" + hv + "&field3=" + stv +
"&field4=" + dv + "&field5=" + lv + "&field6=" + vv +
"&field7=" + iv + "&field8=" + pv;
http.begin(url1); http.GET(); http.end();
String url2 = String(tsServer) + "/update?api_key=" + key2 +
"&field1=" + efficiency + "&field2=" + fault_probability +
"&field3=" + (fault_message == "DUST ACCUMULATION!") +
"&field4=" + (fault_message == "CRITICAL FAULT!") +
"&field5=" + (fault_message == "Warning");
http.begin(url2); http.GET(); http.end();
}
```

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