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Smart Solar Energy Monitoring and Management using IoT and Microcontrollers

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Abstract: A novel solar energy monitoring system harnesses the strengths of Raspberry Pi, NodeMCU ESP8266, and Arduino Uno to optimize renewable energy management. By leveraging Raspberry Pi's processing power for centralized data analysis and integrating NodeMCU and Arduino Uno for enhanced sensor data collection, this system achieves precise monitoring, scalability, and flexibility. This collaborative approach enables seamless integration with various peripherals and communication protocols, streamlining solar energy management and maximizing efficiency and sustainability.

Introduction:

[1]The world is shifting towards renewable energy, with solar power at the forefront. Solar panels, harnessing the photovoltaic effect, convert sunlight into electricity, providing a clean and sustainable source of power. Technological advancements have yielded compact sensors and innovative networking solutions, enhancing renewable energy efficiency. This project explores solar power harvesting, Raspberry Pi-based networking, compact sensor integration with Arduino Uno, NodeMCU, and Raspberry Pi, and ThinkSpace's role in energy monitoring. By leveraging these technologies, we can create sustainable energy systems that benefit society and the environment.

[2]A building energy monitoring system utilizes LoRa modulation and MQTT protocol to optimize energy consumption. The system consists of sensor nodes that track electrical power data, comprising Arduino Uno, LoRa Shield, current and voltage sensors, and a relay. These nodes transmit data to a LoRa Gateway, which connects to an IoT cloud server via MQTT protocol. The system enables real-time monitoring and control of energy usage, promoting efficient energy management. Initial experiments used the Thingspeak platform for data visualization, showcasing the system's potential for device control and energy savings. The sensor accuracy was impressive, with minimal error rates.

[3]A cost-effective IoT energy monitoring system has been developed, leveraging affordable components like the PZEM-004T energy meter, non-invasive current transformers, and the ESP8266 Wemos D1 mini microcontroller. This system enables real-time tracking of voltage, current, power, and cumulative energy consumption, making it suitable for various applications, including smart grids, home automation, and electricity billing. The system's design ensures accurate data collection and seamless transmission to servers via the internet, providing valuable insights for energy management and optimization.

[4]The increasing global energy demand, driven by rapid urbanization and population growth, has made energy conservation a pressing concern. Energy monitoring systems have emerged as a vital solution to optimize energy usage, reduce waste, and promote efficient resource utilization. This study reviews existing energy monitoring approaches, highlighting enabling technologies like sensors and mobile devices. It examines practical considerations, performance issues, and the impact of these systems under stress. Key design factors, parameters, and real-world applications are analyzed and compared, revealing common trends and patterns in the field. The findings provide valuable insights into effective energy monitoring and management strategies.

[5]This study presents a cost-effective IoT-based energy monitoring solution, suitable for various applications, including smart grids, home automation, and electricity billing. The system utilizes affordable components, such as the PZEM-004T energy meter and non-invasive current sensors, in conjunction with the ESP8266 Wemos D1 mini microcontroller. This setup enables real-time data collection and transmission to a server via the internet. The results demonstrate the system's ability to accurately track key energy metrics, including voltage, current, power, and cumulative consumption.

Existing system:

The Internet of Things (IoT) is a revolutionary technology that interconnects devices, environments, and objects, facilitating seamless communication and data exchange between them. This interconnected system is supported by key technologies such as Radio Frequency Identification (RFID) and sensor networks, which play a crucial role in enabling the IoT ecosystem.

In the realm of solar energy, IoT-enabled monitoring modules have emerged as a game-changer. These modules track panel performance and environmental factors in real-time, providing valuable insights that optimize energy generation. A sophisticated network comprising photovoltaic (PV) panels, sensors, Arduino Uno, and Raspberry Pi works in tandem to harness solar energy efficiently.

The sensors deployed in this system monitor critical parameters such as irradiance and temperature, which have a direct impact on the performance of the PV panels. The Arduino Uno microcontroller processes the data collected by the sensors and regulates the operation of the panels to ensure maximum energy output.

The Raspberry Pi acts as a central hub, aggregating data from the sensors and providing connectivity to the broader IoT ecosystem. This enables remote monitoring, data analysis, and predictive maintenance, ensuring that the solar energy system operates at peak efficiency. The IoT platform provides a user-friendly interface for accessing real-time data, historical performance metrics, and system diagnostics.

By leveraging the power of IoT technology, this interconnected system promotes sustainability, resilience, and data-driven decision-making in energy management. It enables users to optimize energy utilization, reduce waste, and predict potential issues before they occur. The system's capabilities include real-time monitoring, predictive maintenance, and optimized energy generation, making it an effective solution for solar energy management.

The integration of IoT technology in solar energy systems has the potential to transform the way we generate, distribute, and consume energy. By harnessing the power of data analytics and real-time monitoring, we can create a more sustainable and resilient energy infrastructure that meets the needs of the present without compromising the future.

Proposed system:

A sophisticated solar energy monitoring and management system is designed to optimize energy generation and efficiency. The system comprises multiple photovoltaic (PV) panels equipped with advanced sensors, including UV sensors, temperature sensors, and voltage sensors. These sensors continuously monitor environmental conditions and panel performance, providing valuable insights into solar irradiance levels, temperature fluctuations, and electrical output.

The sensor data is transmitted to a NodeMCU microcontroller, which serves as the local control unit. The NodeMCU aggregates and processes the sensor data, executing control algorithms to ensure optimal energy production. The processed data is then transmitted to a Raspberry Pi, which acts as the central processing unit for the entire system.

The Raspberry Pi hosts software applications and services for real-time monitoring, data visualization, and system control. It enables connectivity to external networks and cloud-based IoT platforms, allowing for remote access and management of the solar energy system. This setup provides users with a comprehensive overview of system performance, enabling data-driven decision-making and optimized energy management.

By integrating multiple sets of PV panels with advanced sensors and control units, the system enables precise monitoring, analysis, and control of solar energy production. This contributes to a more sustainable and resilient energy infrastructure, ultimately promoting efficient energy utilization and reduced environmental impact. The system's capabilities include real-time monitoring, predictive maintenance, and optimized energy generation, making it an effective solution for solar energy management.

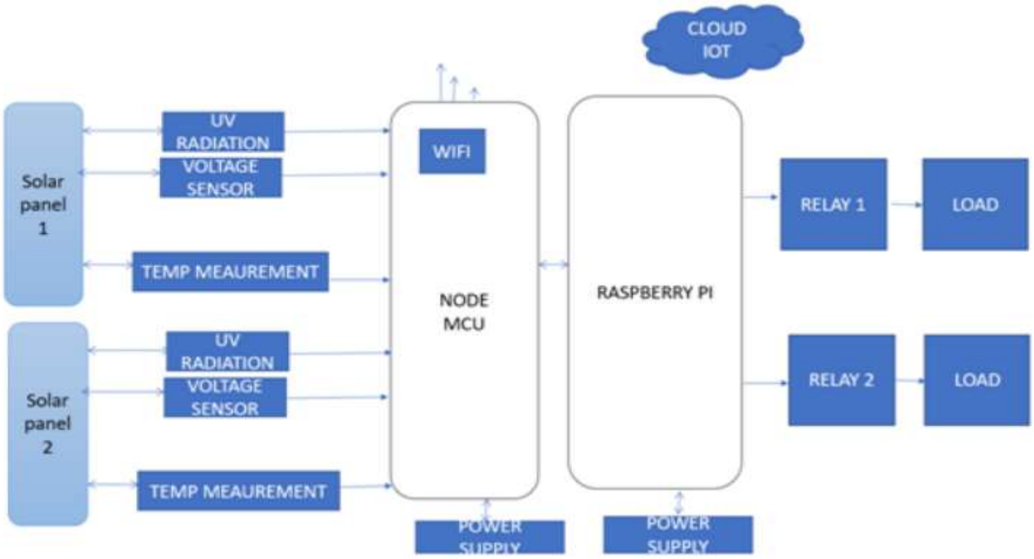

Fig: Block Diagram of Proposed System – Transmitter End

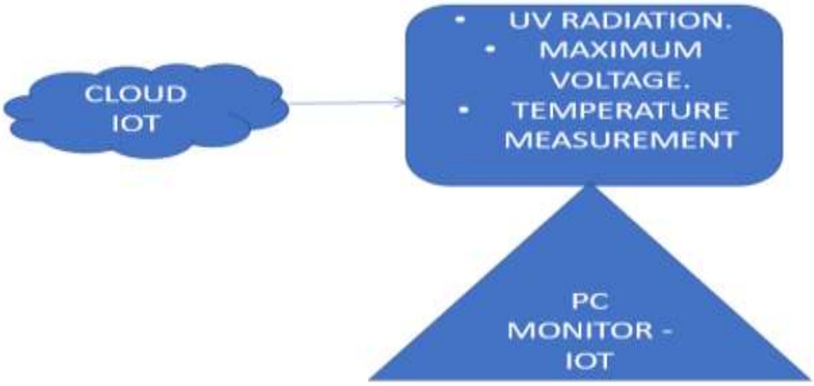

Fig: Block Diagram of Proposed System – Receiver End

Arduino Programme:

```
#include <SoftwareSerial.h>
#include <DHT.h>
// Hardware pin definitions
int UVOUT1 = A0; // Output from the first UV sensor
int ENABLE1 = A1; // Enable pin for the first UV sensor
int UVOUT2 = A2; // Output from the second UV sensor
int ENABLE2 = A3; // Enable pin for the second UV sensor
const int sensorPin1 = A4; // Analog pin for sensor 1
const int sensorPin2 = A5; // Analog pin for sensor 2
int relay1 = 8;
int relay2 = 9;
// DHT Sensor pin
#define DHTPIN1 2 // Pin for first DHT11 sensor
#define DHTPIN2 3 // Pin for second DHT11 sensor
#define DHTTYPE DHT11 // DHT 11
SoftwareSerial mySerial(6, 7); // RX, TX (specify appropriate pins)
DHT dht1(DHTPIN1, DHTTYPE);
DHT dht2(DHTPIN2, DHTTYPE);
void setup()
{
 Serial.begin(9600);
 mySerial.begin(9600); // Match baud rate with Arduino
```

```
 pinMode(UVOUT1, INPUT);
 pinMode(ENABLE1, OUTPUT);
 pinMode(UVOUT2, INPUT);
pinMode(ENABLE2, OUTPUT);
 pinMode(relay1, OUTPUT);
 pinMode(relay2, OUTPUT);
 dht1.begin();
 dht2.begin();
 digitalWrite(ENABLE1, HIGH); // Enable the first UV sensor
 digitalWrite(ENABLE2, HIGH); // Enable the second UV sensor
 Serial.println("ML8511 example");
}
void loop()
{
 int uvLevel1 = averageAnalogRead(UVOUT1);
 int uvLevel2 = averageAnalogRead(UVOUT2);
 int sensorValue1 = analogRead(sensorPin1); // Read the analog voltage from
sensor 1
 int sensorValue2 = analogRead(sensorPin2); // Read the analog voltage from
sensor 2
 float voltage1 = sensorValue1 / 39.50; // Convert the analog value to voltage
for sensor 1
 float voltage2 = sensorValue2 / 39.50; // Convert the analog value to voltage
for sensor 2
 // Read temperature and humidity from DHT sensors
 float temp1 = dht1.readTemperature();
 float temp2 = dht2.readTemperature();
 // Convert the voltage to UV intensity level for sensor 1
 float uvIntensity1 = mapfloat(uvLevel1, 0, 1023, 0.0, 15.0);
 // Convert the voltage to UV intensity level for sensor 2
 float uvIntensity2 = mapfloat(uvLevel2, 0, 1023, 0.0, 15.0);
// Send data to NodeMCU
 Serial.print("UV1: ");
 Serial.print(uvIntensity1);
 Serial.print(", UV2:");
 Serial.print(uvIntensity2);
 Serial.print(", Voltage Sensor 1: ");
 Serial.print(voltage1);
 Serial.print(", Voltage Sensor 2: ");
 Serial.print(voltage2);
 Serial.print(", Temp1: ");
 Serial.print(temp1);
 Serial.print(", Temp2: ");
 Serial.println(temp2);
 // Send data to NodeMCU
 mySerial.print("UV1:");
 mySerial.print(uvIntensity1);
 mySerial.print(", UV2:");
 mySerial.print(uvIntensity2);
 mySerial.print(", Voltage1:");
 mySerial.print(voltage1);
 mySerial.print(", voltage2:");
 mySerial.print(voltage2);
 mySerial.print(", Temp1: ");
```

```
 mySerial.print(temp1);
 mySerial.print(", Temp2: ");
 mySerial.println(temp2);
 delay(1000);
if(voltage1 > 5 )
{
digitalWrite(8,LOW);
}
else{
 digitalWrite(8,HIGH);
}
if( voltage2 > 5 ){
 digitalWrite(9,LOW);
}
else{
 digitalWrite(9,HIGH
 );
}
}
// Takes an average of readings on a given pin
// Returns the average
int averageAnalogRead(int pinToRead)
{
 byte numberOfReadings = 8;
 unsigned int runningValue = 0;
 for (int x = 0; x < numberOfReadings; x++)
 runningValue += analogRead(pinToRead);
 runningValue /= numberOfReadings;
 return (runningValue);
}
float mapfloat(float x, float in_min, float in_max, float out_min, float out_max)
{
 return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
}
```

Conclusion:

Raspberry Pi-based solar power monitoring outshines LoRa network monitoring due to its numerous benefits. With robust computational capabilities, Raspberry Pi enables advanced data processing, storage, and analysis locally. This centralized platform offers scalability and comprehensive monitoring, surpassing LoRa's primary focus on long-range communication.

A trio of controllers - NodeMCU ESP8266, Arduino Uno, and Raspberry Pi - work together to enhance monitoring efficiency. NodeMCU and Arduino Uno excel in collecting and processing sensor data, while Raspberry Pi coordinates data aggregation and analysis. This collaborative approach ensures precise monitoring, scalability, and flexibility.

Raspberry Pi's versatility allows seamless integration with various peripherals and networking options, making it compatible with diverse sensor arrays and communication protocols. This setup provides a superior solution for efficient and comprehensive solar energy management, enabling optimized performance and data-driven decision-making.

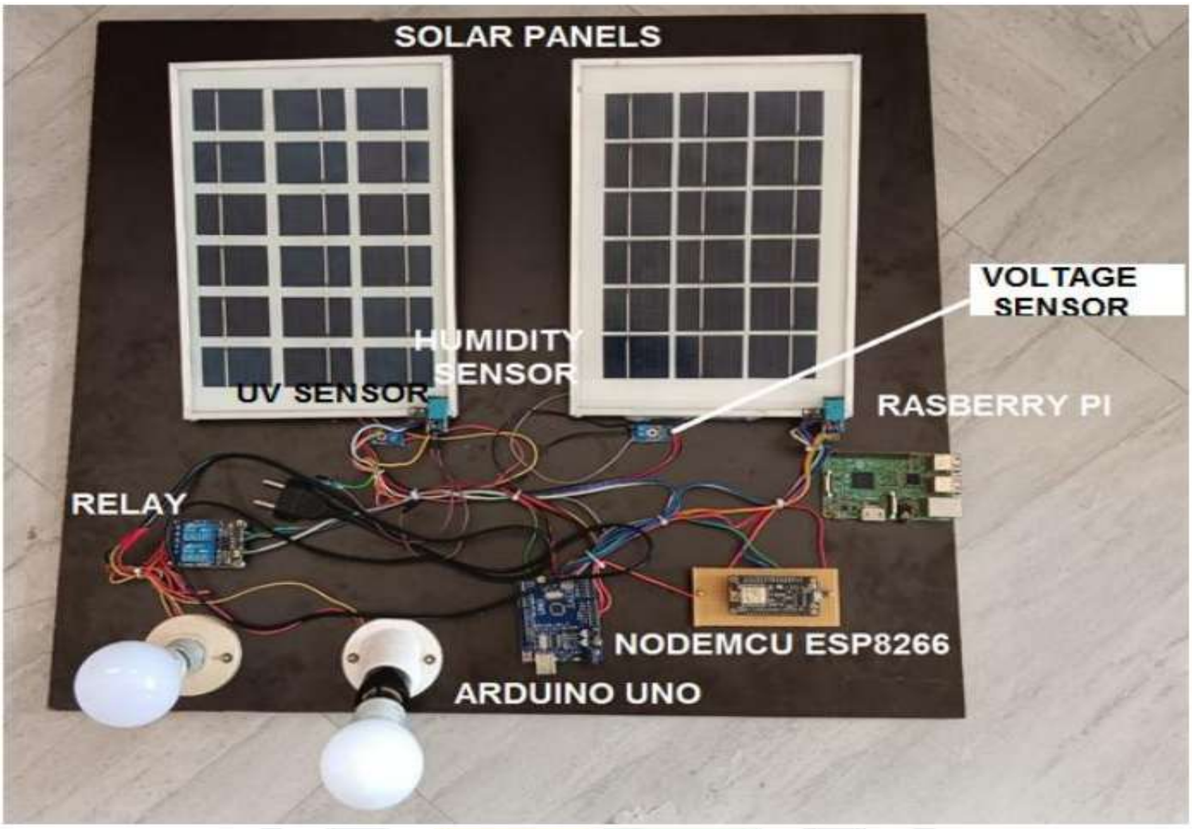

Fig: Hardware setup of Proposed System

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