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Smart Solar Power Irrigation System with IoT Monitoring and Control

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ABSTRACT: This project presents a smart solar-powered irrigation system integrated with IoT monitoring for efficient water management in agriculture. It uses solar energy to operate the irrigation system, reducing dependency on conventional electricity. Soil moisture sensors are employed to measure the water content in the soil in real time. Based on sensor data, the system automatically controls the water pump to irrigate crops only when needed. IoT technology enables remote monitoring and control through a mobile or web application. This helps farmers make better decisions and conserve water resources. The system is cost-effective, eco-friendly, and suitable for rural areas. It reduces manual labour and improves crop productivity. Overall, the project promotes sustainable and intelligent farming practices.

KEYWORDS: smart irrigation, solar energy, IoT, soil moisture, Blynk IoT, Automation

I.INTRODUCTION

A smart solar-powered irrigation system with IoT monitoring is an advanced solution designed to improve agricultural efficiency while conserving water and energy. Traditional irrigation methods often lead to excessive water usage and require manual operation, which can be time-consuming and inefficient. By integrating solar energy and Internet of Things (IoT) technology, this system enables automated irrigation based on real-time environmental conditions, making farming more sustainable and cost-effective.

The system utilizes solar panels to generate renewable energy, reducing dependence on conventional electricity sources. This makes it especially useful in rural and remote areas where power supply may be limited or unreliable. Sensors such as soil moisture, temperature, and humidity sensors continuously monitor field conditions and send data to a microcontroller, which processes the information and determines the optimal irrigation schedule.

IoT connectivity allows farmers to monitor and control the irrigation system remotely through mobile applications or web platforms. This real-time monitoring ensures that crops receive the right amount of water at the right time, preventing both over-irrigation and water scarcity. Alerts and data analytics further help farmers make informed decisions, improving crop yield and resource management.

Overall, the smart solar-powered IoT-based irrigation system represents a modern approach to agriculture that combines renewable energy and intelligent automation. It not only enhances productivity but also promotes environmental sustainability by conserving water and reducing energy consumption. This technology plays a crucial role in addressing the growing challenges of food security and climate change.

II. LITERATURE REVIEW

The development of smart irrigation systems using solar energy and IoT has gained significant attention in recent years due to the increasing demand for water conservation and sustainable agriculture's. Angel et al. (2025) proposed a smart solar-powered IoT-based automatic irrigation system integrated with rainwater harvesting. Their system efficiently combines renewable energy with water conservation techniques, improving irrigation efficiency while reducing dependency on conventional power sources. Matthew Kwofie et al. (2023) focused on the utilization of solar energy for water pumping in agriculture. Their work highlights how solar-powered pumps can replace traditional electric and diesel pumps, making irrigation systems more cost-effective and environmentally friendly. S. D. Yusuf et al. (2022) developed and simulated a solar-powered smart irrigation system using IoT and the Blynk mobile application. Their system enables real-time monitoring and control, allowing farmers to manage irrigation remotely. Jessica Donggayao

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Salwaga (2025) conducted a case study on solar-powered irrigation systems in specific agricultural regions. The study demonstrates the practical implementation and effectiveness of solar irrigation in real-world farming environments.

Sani Theo (2023) emphasized sustainable agriculture through solar-powered irrigation systems. The research focuses on improving farming productivity while reducing environmental impact using renewable energy sources. Harishankar Suresh et al. (2014) presented an early design of a solar-powered smart irrigation system. Their work laid the foundation for integrating solar energy into irrigation systems and highlighted its feasibility. The UK Essays (2020) report discussed a solar-powered smart irrigation monitoring system using IoT. It introduced remote monitoring and control features, which are essential in modern precision agriculture. A. Kumar et al. (2019) designed an IoT-based irrigation system using soil moisture sensors. The system automates irrigation based on soil conditions, reducing water wastage. Patel et al. (2021) implemented an automatic irrigation system using Arduino and solar power. Their work demonstrates a low-cost and efficient embedded solution for agricultural applications. S. Karthick et al. (2022) proposed a smart irrigation system using IoT and cloud computing. Their system enhances data storage and analysis capabilities, enabling better decision-making. Smith et al. (2020) focused on designing solar-powered water pumping systems. Their study is useful for selecting appropriate solar panels and pump capacities for irrigation. Ramesh et al. (2018) introduced a wireless sensor network-based irrigation system, enabling large-scale monitoring of agricultural fields. Verma et al. (2019) discussed automation in agriculture using IoT technologies. Their work highlights the importance of smart systems in modern farming. Johnson (2021) emphasized efficient water management using smart irrigation systems, focusing on minimizing water usage and maximizing crop yield. N. Gupta et al. (2020) explored various applications of solar energy in agriculture, including irrigation, drying, and storage systems. K. Elangovan et al. (2022) developed a Blynk-based smart irrigation system using ESP32. This approach is highly relevant for mobile-controlled irrigation systems. S. Mohan et al. (2021) proposed an IoT-enabled precision agriculture system that improves farming accuracy through data-driven decisions. A. Rahman et al. (2020) designed a low-cost irrigation system using Arduino and GSM technology, enabling remote control even without internet connectivity. D. Singh et al. (2023) introduced smart farming systems using IoT and machine learning, providing advanced automation and predictive analysis. M. Ali et al. (2019) designed a solar-powered drip irrigation system, which improves water efficiency and crop productivity. R. Sharma et al. (2018) developed a simple automatic irrigation system using soil moisture sensors, suitable for small-scale applications. L. Thomas (2021) proposed an IoT-based agriculture monitoring system for tracking crop conditions in real time. H. Lee et al. (2019) focused on smart water management systems using IoT sensors to optimize water usage. P. Reddy et al. (2022) designed a solar-powered smart agriculture monitoring system combining renewable energy and IoT technologies. B. Kumar et al. (2023) presented a complete IoT-based irrigation system design, covering both hardware and software implementation.

III. INTERNET OF THINGS (IoT)

Internet of Things (IoT) refers to a network of physical devices embedded with sensors, software, and communication technologies that enable them to collect and exchange data over the internet. These devices can range from simple sensors to complex machines and are designed to operate with minimal human intervention. IoT allows objects to sense their environment, process information, and communicate with other devices, creating a smart and connected ecosystem. IoT systems typically consist of sensors for data collection, microcontrollers or processors for data processing, and communication modules such as Wi-Fi, Bluetooth, or GSM for transmitting data. The collected data is often sent to cloud platforms where it is analysed and used to make intelligent decisions. Applications of IoT are widely seen in smart homes, healthcare, industrial automation, and agriculture, where systems can monitor conditions in real time and respond automatically. In agriculture, IoT plays a crucial role in improving productivity and resource management. For example, IoT-based irrigation systems use soil moisture sensors to determine the water requirements of crops and automatically control water supply. This helps in reducing water wastage, saving energy, and increasing crop yield. Overall, IoT technology supports efficient, cost-effective, and sustainable solutions across various sectors.

IV. RENEWABLE ENERGY SYSTEM

Renewable energy sources are natural resources that are replenished continuously by nature.
They are considered sustainable and environmentally friendly compared to fossil fuels.
Common examples include solar, wind, hydro, biomass, and geothermal energy.
Solar energy is obtained from sunlight using photovoltaic panels or solar collectors.
Wind energy is generated by using wind turbines to convert air movement into electricity.
Hydropower uses flowing water to produce energy through dams or turbines.

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Biomass energy is derived from organic materials like plant and animal waste.
Geothermal energy comes from heat stored beneath the Earth's surface.
Overall, renewable energy helps reduce pollution, conserve resources, and support sustainable development.

V. BLOCK DIAGRAM

A block diagram is a simplified graphical representation of a system that shows its major components and the flow of signals or data between them. Each block represents a functional unit, such as sensors, microcontroller, power supply, or output devices, and arrows are used to indicate the direction of information flow. In a smart irrigation system, the block diagram typically includes input sensors (like soil moisture and temperature sensors), a processing unit (such as a microcontroller or IoT module), communication modules for data transmission, and output devices like pumps or valves. This representation helps in understanding the overall system structure, working principle, and interaction between different components in a clear and organized manner.

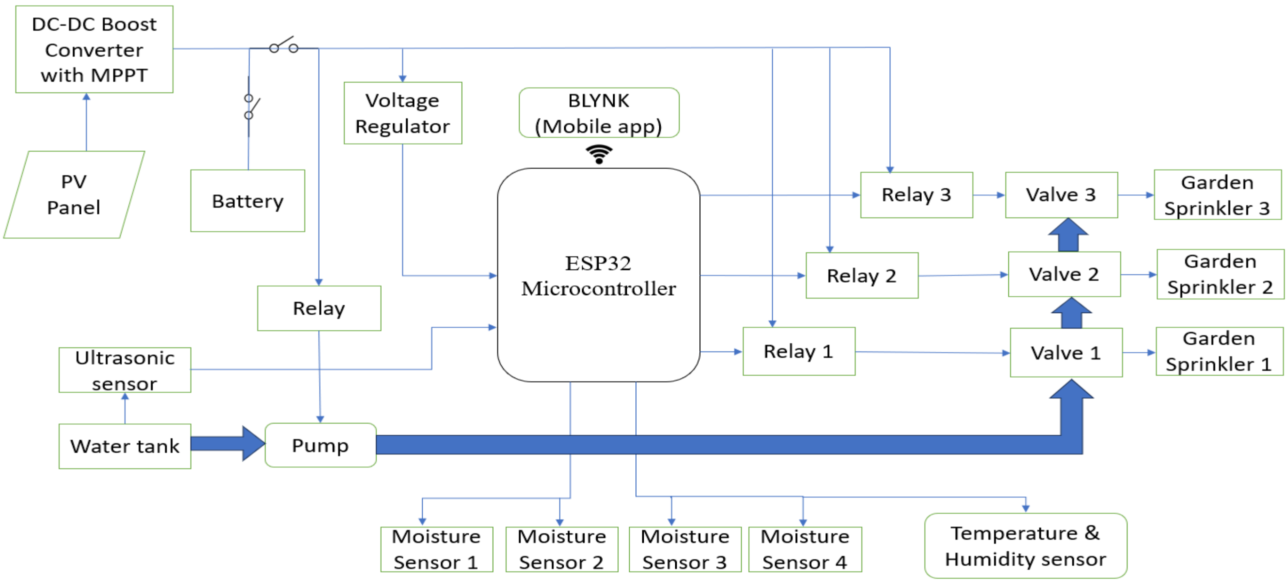

Fig.5.1.Block Diagram

VI. HARDWARE SET OF SMART SOLAR POWER IRRIGATION SYSTEM WITH IOT MONITORING AND CONTROL

The hardware of a smart solar-powered IoT irrigation system consists of several interconnected components designed to provide efficient, automated, and sustainable irrigation. The primary power source is a solar panel, which converts sunlight into electrical energy. This energy is stored in a rechargeable battery to ensure uninterrupted operation even during nighttime or cloudy conditions. A charge controller is used to regulate the voltage and current from the solar panel, protecting the battery from overcharging and deep discharge.At the core of the system is a microcontroller such as ESP32 or Arduino, which acts as the brain of the system. It processes input data from various sensors and controls the operation of output devices. Soil moisture sensors are used to measure the water content in the soil, while temperature and humidity sensors monitor environmental conditions. These sensors continuously send real-time data to the microcontroller.

A relay module is used to switch the water pump ON or OFF based on the sensor readings. When the soil moisture level falls below a set threshold, the microcontroller activates the relay to start the pump, ensuring timely irrigation. Communication modules like Wi-Fi or GSM are integrated to transmit data to cloud platforms or mobile applications, allowing users to monitor and control the system remotely.Additional components such as pipes, valves, and water pumps form the irrigation mechanism. Together, these hardware elements create a reliable, energy-efficient, and automated irrigation system that reduces water wastage and enhances agricultural productivity.

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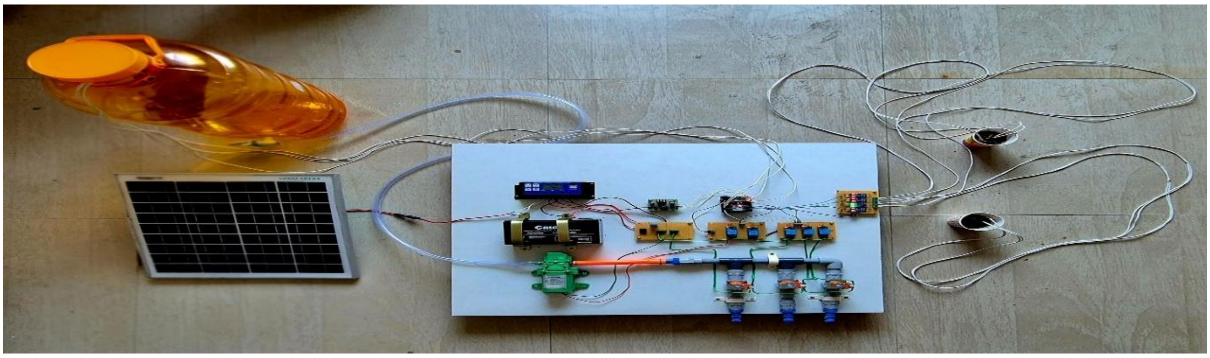

Fig.6.1.Hardware Setup Smart Solar Power Irrigation System with IoT Monitoring and Control

1. Solar Panel
Converts sunlight into electrical energy using photovoltaic cells. Provides a renewable and eco-friendly power source for the system.

2. Battery
Stores excess solar energy for use during night or low sunlight conditions. Ensures continuous power supply to the irrigation system.

3. Charge Controller
Regulates voltage and current from the solar panel to the battery. Prevents overcharging and deep discharge of the battery.

4. Microcontroller (Arduino/Node MCU)
Acts as the brain of the system and processes sensor data. Controls the pump and communication based on programmed logic.

5. Soil Moisture Sensor
Detects the water content present in the soil. Sends real-time data to the microcontroller for irrigation decisions.

6. Water Pump
Pumps water to the field when irrigation is required. Operates automatically based on soil moisture levels.

7. Relay Module
Acts as a switch to control the water pump electrically. Receives signals from the microcontroller to turn the pump ON/OFF.

8. IoT Module (Wi-Fi/GSM)
Enables remote monitoring and control via internet connectivity. Sends data to mobile or web applications for user access.

9. Mobile/Web Application
Displays real-time data such as soil moisture and system status. Allows users to monitor and control the irrigation system remotely.

VII. HARDWARE IMPLEMENTATION

The hardware implementation of the smart solar irrigation system integrates renewable energy with automated control technologies. A solar panel is used to convert sunlight into electrical energy required for system operation. The generated power is regulated by a charge controller to maintain a stable voltage supply. This energy is stored in a rechargeable battery to ensure continuous functioning even during low sunlight conditions. A microcontroller such as Arduino or Node MCU acts as the central processing unit of the system. Soil moisture sensors are placed in the field to monitor the water content in the soil continuously. The sensor data is transmitted to the microcontroller for analysis and decision-making. Based on the moisture level, the controller determines whether irrigation is necessary. A relay module is used as a switching device to control the water pump. The water pump is activated automatically to supply water to the crops when required. An IoT module is integrated to enable real-time monitoring and remote control of the system. Overall, the hardware setup ensures efficient water usage, reduces manual effort, and supports sustainable agricultural practices.

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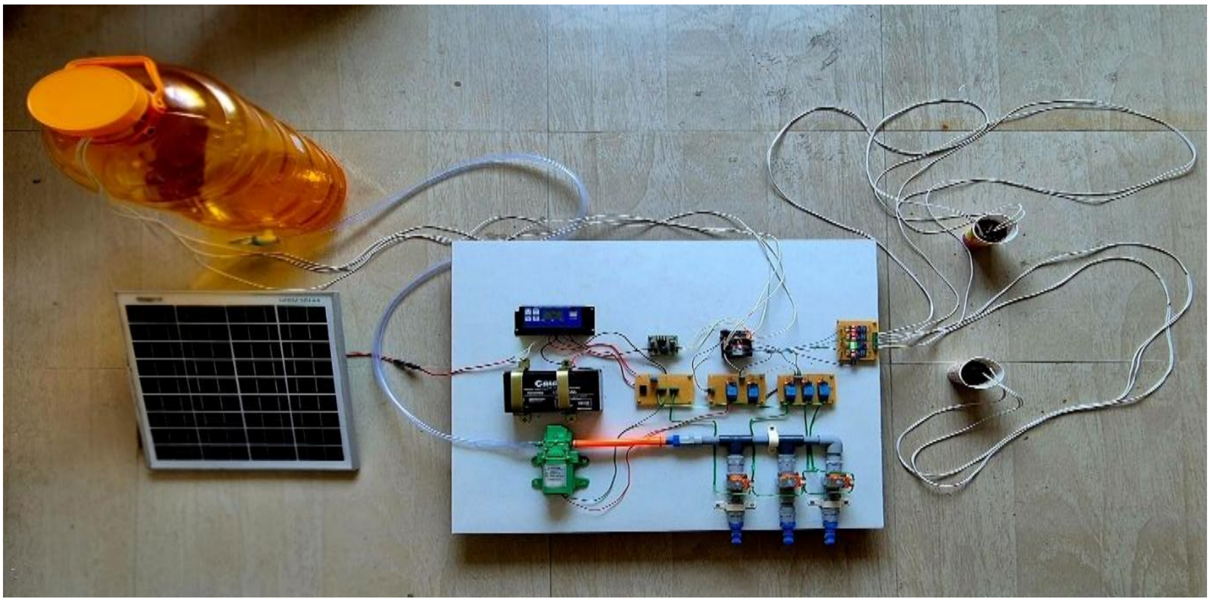

Fig.7.1.Hardware Implementation of smart solar power irrigation system

WORKING MODES

1.AutomaticMode

The system operates based on soil moisture sensor readings.
The water pump turns ON/OFF automatically depending on soil conditions.

2.ManualMode

The user can control the water pump manually through a mobile or web application.
This mode is useful for immediate irrigation or system testing.

3.MonitoringMode

The system continuously collects and displays data such as soil moisture and pump status.
Users can monitor real-time information remotely using IoT technology.

VIII. RESULT AND DISCUSSION

The results of the smart solar power irrigation system demonstrate efficient and reliable performance in agricultural applications. The system successfully utilized solar energy to operate without dependence on conventional electricity. Soil moisture sensors accurately measured the water content in the soil and provided real-time data. Based on this data, the irrigation process was automatically controlled, reducing unnecessary water usage. The water pump operated effectively through the relay mechanism whenever irrigation was required. The integration of IoT technology enabled remote monitoring and control of the system. Users were able to view system status and soil conditions through a mobile or web application. The system helped in conserving water and improving irrigation efficiency. It also reduced manual labor and human intervention in farming activities. The overall performance was stable under different environmental conditions. The project proved to be cost-effective and suitable for rural areas. Thus, the system supports sustainable agriculture and smart farming practices.

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TEST CONDITION	SOIL MOISTURE (START,%)	PUMP RUN TIME (SEC)	WATER DISPENSED (ML)	FINAL MOISTURE (%)
Dry soil (initial 15 %)	15	5	150	82
Semi-dry (30%)	30	3	70	75
After rain (70%)	70	0	0	70

IX. CONCLUSION

This paper presented a complete design and implementation of an IoT-based solar-powered smart irrigation system using ESP32. The integration of renewable energy, MPPT technology, and sensor-based automation provides an efficient and sustainable irrigation solution. The system successfully reduces water wastage, minimizes manual intervention, and promotes sustainable agricultural practices. It is suitable for rural, remote, and urban farming applications.

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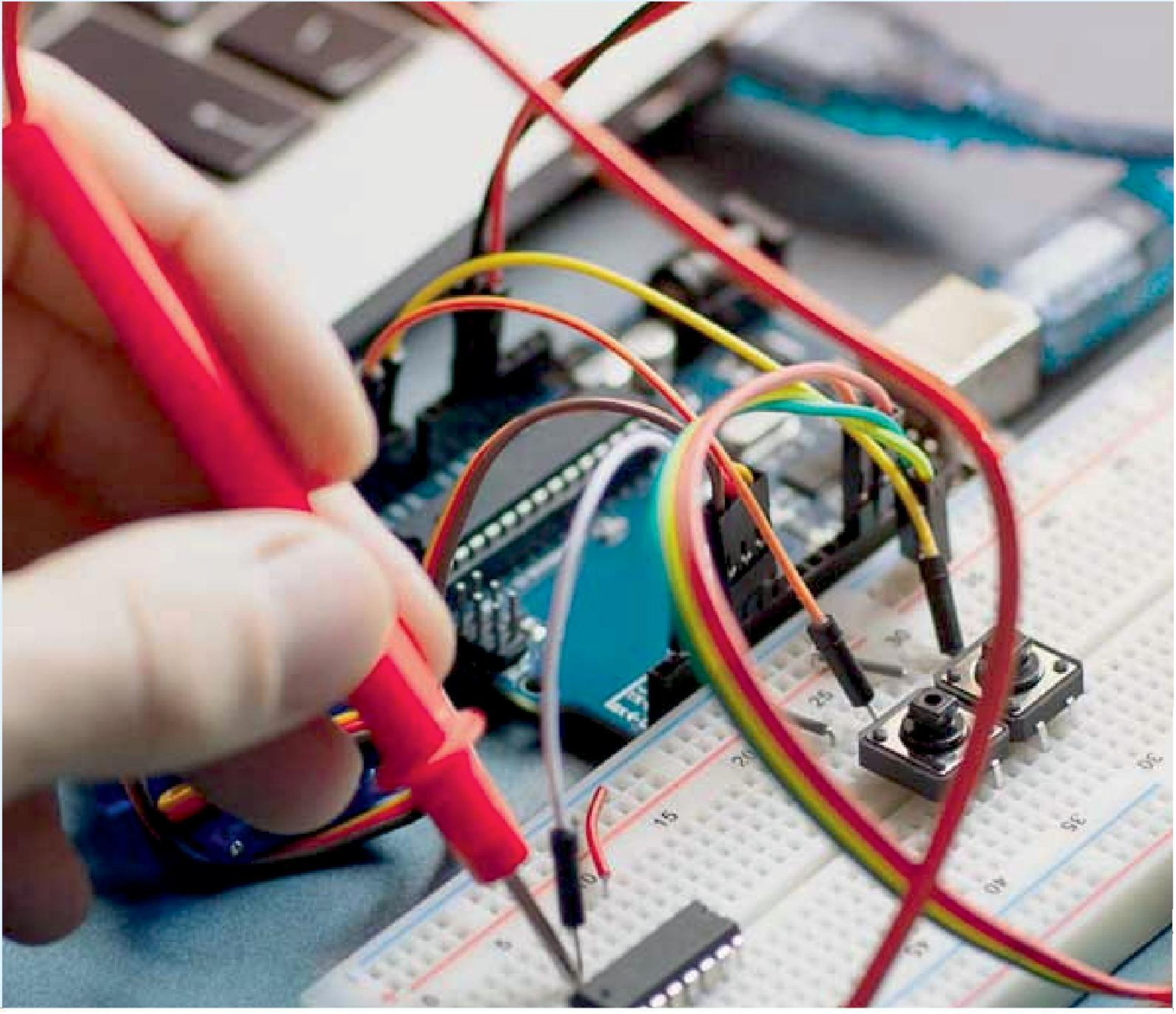

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