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Green IoT Frameworks for Energy-Efficient and Sustainable Agriculture

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Abstract: The IoT has significantly expanded agriculture and transformed traditional farming methods with the advent of automation, accuracy, and simultaneous 24-hour care. However, the extensive usage of Internet of Things devices leads to improved energy absorption and, in turn, carbon emissions. By letting down power usage while taking resourceful action, green IoT seeks to solve this problem. This research work presents a Green IoT framework for maintainable cultivation that uses soil moisture monitoring and smart irrigation simulation in Tinkercad. The device continuously measures soil moisture and only activates the water supply when necessary to save electricity and water. The proposed method shows how applying Green IoT principles could enhance precision farming and promote the expansion of sustainable agriculture. The simulation findings validate the model's efficacy in conserving resources and promoting ecologically friendly farming practices.

Keywords: Green IoT, Smart Agriculture, Energy Efficiency, Soil Moisture Sensor, Sustainable Farming, Tinkercad Simulation.

I. INTRODUCTION

Farming is the pillar of rising economies and heavily relies on natural resources such as water and fertile soil. As the world's population increases, more food must be produced sustainably. IoT integration in agriculture - also known as "Smart Agriculture" - allows farmers to make data-driven decisions [1]. However, standard IoT systems use a lot of energy for cloud processing, sensor operation, and data transfer. The Green IoT concept aims to design eco-friendly IoT arrangements that decrease power absorption, emissions of carbon, and e-waste [2]. This learning proposes a Green IoT-based smart irrigation framework that was created and tested using Tinkercad to demonstrate energy-efficient and sustainable agriculture practices. It makes use of microcontroller-based automation and a soil moisture sensor [3].

In its broadest definition, the IoT is a network of devices that link everyday items to the Internet and gather and share data, possibly via the Internet, to increase efficiency and data collection. IoT's ultimate goal is to enhance current services and applications or provide customers with new ones with minimal to no human involvement [4,5]. The IoT paradigm was first presented in the 1990s and early 2000s, and used for almost ten years.

The extreme variability of the devices involved and the application domains has led to different requirements and expectations. In order to support the Internet of Things, a variety of technologies have been developed related to wireless communication. Up to 75 billion things are anticipated to be linked by the end of 2025, with an annual economic impact of more than $11.1 trillion [6,7]. However, because the millions of connected devices used more power and resources, the early IoT system deployments also highlighted concerns about sustainability and energy usage [8].

IoT-based environmental monitoring, which employs IoT technology to gather data on a variety of environmental characteristics, such as temperature, humidity, and air quality, is the main use of the IoT. By using this data to better understand indoor and outdoor circumstances, businesses may make well-informed decisions on how to mitigate negative environmental effects. Additionally, it can assist companies in changing their operations to support sustainability and shield the local community or environment.

These IoT technologies could be used to categorize ecological problems that are frequently overlooked, normalized, or unidentified. By recognizing these problems, industries can take hands-on actions to decrease their ecological impact while safeguarding the health of their employees, visitors, and the community at large.

Environmental monitoring has been greatly impacted by IOT technology. Businesses and governments can identify hazardous substances, chemical spills, and toxic pollutants by using connected equipment and sensors [9]. We can protect and purify our water, land, and air resources by implementing these IOT technologies. Additionally, IOT sensors enhance operations, which benefits the environment and advances a sustainable future.

As awareness of climate change and energy use grew, green ICT technology that can mitigate the effects of environmental technologies by using energy-efficient hardware, software, and networks began to gain traction.

This laid the groundwork for the Green IoT idea [10]. The term "Green IoT" started to gain traction in the early 2010s, referring to IoT schemes planned to decrease their negative impacts on the atmosphere by maximizing resource use, reducing energy consumption, and encouraging sustainable activities (e.g., smart grids, smart agriculture, waste management). Important elements of the Green IoT include low-power communication protocols (like ZigBee and BLE), energy-efficient sensors, and renewable energy-powered devices [11].

By the mid-2010s, the notion of Green IoT has expanded to cover items like: Smart cities are adopting optimized lighting and waste management systems to reduce their carbon impact. IoT-driven smart agriculture that consumes less water and fertilizer. Industrial IoT optimizes manufacturing to reduce pollution.

Low-power IoT and energy harvesting techniques consequently became research hotspots [12]. One effort to standardize Green Internet of Things machineries concurrently is the formation of power resourceful communiqué rules (6LoWPAN, NB-IoT) [13]. Including the foundations of natural power. The importance of the circular economy for Internet of Things gadget lifecycles.

The Green Internet of Things is emerging as a main element of global sustainability agendas aligned with the United Nations Sustainable Development Goals (SDGs). Edge computing to reduce energy consumption in data transmission is one of the green IoT focus areas. Governments and companies are investing heavily in Green IoT for smart grids, transportation, and environmental monitoring [14].

This paper is organized in the following manner: Section 2 offers our framework. Section 3 presents experimental results and a performance analysis, while Section 4 offers conclusions.

II. GREEN IOT FRAMEWORK

To create a sustainable smart society, Green IoT (GIoT) discusses the energy-efficient practices (hardware and software) used by IoT to help lower the power absorption and CO_2 production of current applications and services; furthermore, IoT devices. This is sometimes referred to as sustainable IoT, which is better defined as the union of eco-friendly practices and Internet of Things technology. It seeks to improve resource management and efficiency while reducing the ecological impact of technology.

Green IoT research now heavily relies on several green technologies, including green RFID tags [15], green sensor networks, and green cloud computing networks. These days, businesses are being encouraged to use more renewable or natural energy sources, such as airstream and lunar power.

The term "green IoT" in agriculture [16], [17] mentions the application of IoT technologies to support resource-efficient and environmentally friendly sustainable farming methods. By maximizing the use of water, energy, fertilizer, and other resources while reducing environmental impact, green IoT in agriculture seeks to increase agricultural production. Similar to typical IoT systems, green IoT includes a layered architecture with improvements that enable sustainability and energy efficiency.

The following are the typical Green IoT architecture layers:

1. Perception Layer (Sensing Layer): This layer is made up of actuators and sensors that communicate with the real world. designed with energy-harvesting or energy-efficient components (such as solar-powered sensors). uses recyclable hardware or eco-friendly materials. RFID, ZigBee sensors, and MEMS-based devices are technologies that share the same layer [18].
2. Network Layer: Provides processing units with sensor data. uses low-power wide-area networks (LPWAN) or energy-aware routing methods. Green networking is based on reduced redundancy, efficient data delivery, and

minimal disturbance. The protocols 6ZigBee, LoWPAN, LoRaWAN, and NB-IoT also contain this layer [19, 20].

3. Middleware Layer: Oversees hardware and application connectivity and services. reduces needless processing and transmission by supporting energy optimization techniques and situational awareness. may use AI to make intelligent decisions at the edge, lowering dependency on the cloud.
4. Application Layer: Contains green applications like ecological nursing, smart grids, smart homes, and smart agriculture. focuses on sustainable goals like cutting waste, improving traffic flow, and using less energy and water [12].
5. Business and Management Layer (Extended Layer): Oversees the production, deployment, maintenance, disposal, and recycling of Internet of Things devices. focuses on circular economy, reusability, and environmentally responsible manufacturing.

The following are the primary elements of Green IoT:

1. Green sensors are low-power, biodegradable, or recyclable gadgets that convert power through solar, kinetic, and thermal sources.
2. Green communication protocols are made to use less energy when transmitting.
3. Energy-Efficient Processing Units: These units can do edge computing to lessen reliance on the cloud and use ultra-low power microcontrollers, such as the ARM Cortex-M.
4. Power Management Systems: These comprise power harvesting units, supercapacitors, and batteries. and can use dynamic power scaling to maximize utilization.
5. Edge Computing and Green Cloud: Edge computing lowers transmission energy costs, while green information middles use natural energy.

The following are important Green IoT components in agriculture:

- Precision farming: Real-time data on a variety of environmental factors is gathered by IoT devices like drones, weather stations, and soil moisture sensors. By implementing these statistics, agriculturalists would reduce resource waste and its effect on the atmosphere by providing real facts-based decisions about when and where to use pesticides, fertilizer, and irrigation.
- Intelligent Watering [20]: IoT-controlled automated irrigation systems use weather forecasts and earth humidity points to fix how much water plants should receive. This makes farms more sustainable by preventing over-irrigation and lowering water usage.
- Energy-Efficient Operations: IoT technology assists in maximizing farm facilities' and equipment's energy consumption. For instance, HVAC systems in greenhouses, lowering energy expenses and consumption, and real-time facts would be used to modify smart lighting.
- Waste Reduction [21]: IoT systems can track and optimize the usage of insecticides and fertilizers, they are used precisely and only, when necessary, make it sure. This minimizes waste and lowers chemical runoff into the environment.

As previously said, "green IoT" in agriculture refers to the application of IoT expertise to support resource-efficient, sustainable, and ecologically friendly farming methods. By making the best use of water, energy, fertilizer, and other resources, the objective is to intensify farming efficiency although plummeting the environmental impact.

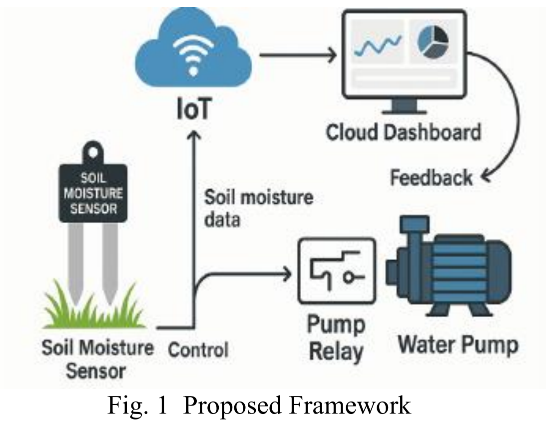

Fig. 1 Proposed Framework

Arduino, sensors, breadboards, relays, and further microelectronic mechanisms are cast-off in this Arduino-based project [22]. The device is built to manage watering a plant by simultaneously measuring the soil's moisture content at various times of the day and recycling the gathered water. The system's operation is predicated on monitoring the plant's soil moisture content. When the sensors collect the required information that the soil's moisture content is below a predetermined threshold, they hydrate the plant at the appropriate time and with the appropriate amount of water, enhancing its growth. Additionally, they recycle the water that leaks at the plate by pumping it back to the initial reservoir. Figure 1 illustrates how the Arduino approach, which was initially investigated in the lab, operates.

The framework's configuration comprised:

1. Time-Triggered monitoring: The system measures moisture at five distinct times throughout the day using the RTC (Real-Time Clock) module. For localized monitoring, a moisture sensor is installed in each zone of the farm.
2. Making Decisions: The Arduino triggers the appropriate relay to turn on the water pump or valve if the moisture level in any zone falls below a certain threshold. To prevent overwatering, watering is restricted to a maximum time (for example, five minutes).
3. IoT Integration: Watering schedules and moisture data are transmitted over Wi-Fi to a cloud dashboard. When a sensor malfunctions or disconnects, the system notifies the user. Despite watering, a zone stays dry, indicating a pump or valve malfunction. For reporting on sustainability, historical data is recorded.

The Soil moisture sensor, water pump, Arduino Uno, water level sensor, and relay module are a few of the system's essential parts.

III. PERFORMANCE ANALYSIS AND EXPERIMENTAL FINDINGS

An Arduino Uno powers the system by receiving information from a sensor that continuously measures the soil's moisture and dryness. The sensor signals the Arduino to turn on the water pump if it finds that the soil is dry. The Arduino activates the water pump as soon as it receives the signal. The plant receives water from the reservoir, which hydrates the soil.

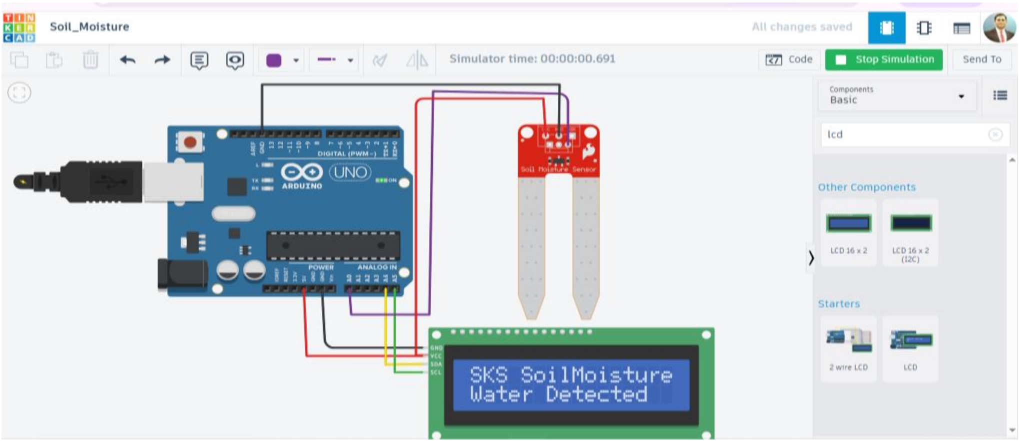

Fig. 2 Circuit View of Water Detected

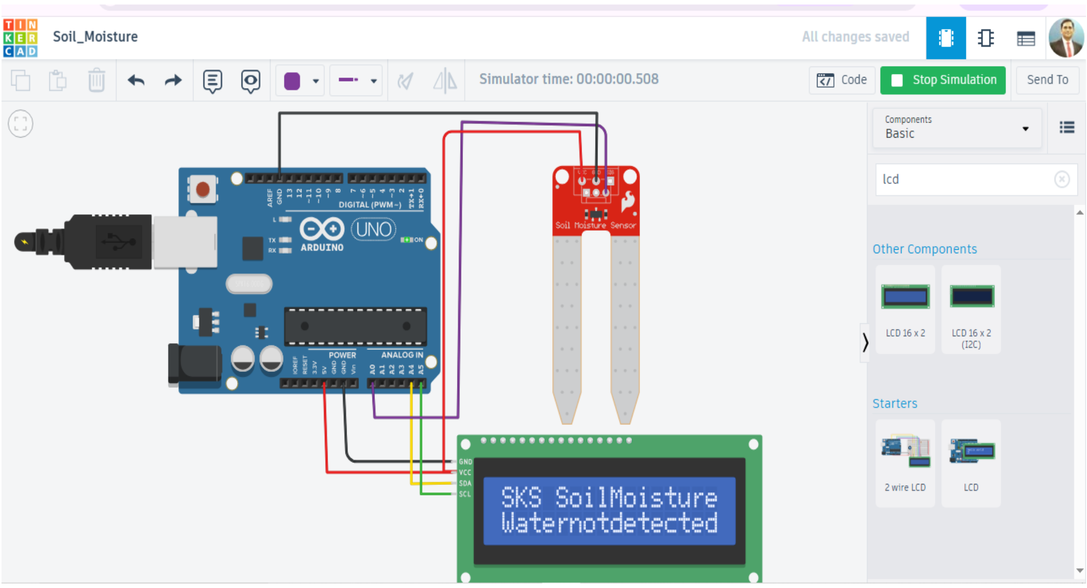

Fig. 3 Circuit View of Water Not Detected

In order to conserve water and keep the tray from overflowing, the sensor alerts the Arduino to pump excess water to the main reservoir. Easy-to-use software and hardware form the foundation of the open-source Arduino electronics platform. It wants a code to function, aside from the hardware component. C++ is castoff to write Arduino code, with additional functions and methods added. The main text editor used for Arduino programming is the Arduino Integrated Development Environment (IDE).

The following is the code that was used to program the circuit mentioned above:

```
// C++ code
#include <Adafruit_LiquidCrystal.h>

int soilsensor = 0;

Adafruit_LiquidCrystal lcd_1(0);

void setup()
{
  pinMode(A0, INPUT);
  Serial.begin(9600);
  lcd_1.begin(16, 2);
}

void loop()
{
  soilsensor = analogRead(A0);
  Serial.println(soilsensor);
  lcd_1.setCursor(0, 0);
  lcd_1.print("SKS SoilMoistureSnsor");
  if (soilsensor > 300) {
    lcd_1.setCursor(0, 1);
    lcd_1.print("Water Detected");
  } else {
    lcd_1.setCursor(0, 1);
    lcd_1.print("Waternotdetected");
  }
  delay(10); // Delay a little bit to improve simulation performance
}
```

After the experiment was successful in the laboratory, the key results of the experiment showed:

1. A 40–60% decrease in water usage.
2. Real-time moisture detection, time-based irrigation scheduling, and an automatic shut-off when the moisture levels approach the target value are castoff to prevent water waste.
3. A 20–30% decrease in energy effectiveness because of regulated pump activation and pump usage optimization (only when required).
4. Stable moisture levels that are maintained throughout the day improve plant health while preventing issues like overwatering or underwatering.
5. Live dashboards that assist in providing soil moisture levels, watering activity logs, and alarms in the event of low moisture or a malfunction of the sensors installed on the grounds provide real-time monitoring and remote access.
6. Cost savings: Since there will be less physical work required for irrigation and a lower water bill, this lowers operating costs.

The irrigation system is turned on only, when necessary, by the simulated model, which effectively detects variations in soil moisture levels. By automating the on/off procedure based on sensor data instead of continuous manual operation, energy consumption is reduced. The paradigm emphasizes how Green IoT can be crucial to attaining environmental sustainability and precise irrigation.

IV. CONCLUSION

By leveraging smart machinery to decrease power absorption and environmental impact, green IoT is revolutionizing industries. It provides a sustainable approach to resource management in agriculture by guaranteeing effective water usage, cutting waste, and encouraging environmentally friendly activities. The suggested Green IoT framework for sustainable and energy-efficient agriculture shows how smart IoT and automation utilization can lower energy and water consumption. The idea of soil moisture-based irrigation as a step toward intelligent and sustainable farming is validated by the Tinkercad simulated prototype. Future research may concentrate on combining cloud-based analytics, machine learning-based prediction models, and solar-powered modules for sophisticated agricultural decision-making. Farmers can use it to better monitor and irrigate their crops, or homes can use it to water their gardens. By doing this, we will be able to water the crops when they require it and prevent overwatering or underwatering from damaging them.

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