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Design and study of smart irrigation system using photovoltaic cells based smart IOT system and weather prediction system for energy and water conservation in India

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Abstract—**India, as an agrarian nation with a population of 1.4 billion, relies heavily on agriculture for livelihoods and food supply. This dependence poses a substantial food security challenge. Furthermore, approximately 90% of our groundwater resources are utilized for crop irrigation, jeopardizing our water security. The conventional reliance on fossil fuels for energy exacerbates environmental issues, contributing to greenhouse gas emissions and air pollution, which are global concerns with far-reaching implications for climate change.In response to these multifaceted challenges, this paper presents a smart irrigation solution. It leverages automated irrigation technology, ensuring that fields receive water precisely when needed. Crucially, this system is powered by photovoltaic (PV) solar cells, rendering it carbon-negative by reducing reliance on fossil fuels. Additionally, the system incorporates rain prediction capabilities, preventing waterlogging and conserving precious groundwater resources. This integrated approach not only addresses food security but also combats air pollution, enhances crop yields, and safeguards vital freshwater sources for future generations.**

Index terms— ***IOT, moisture sensor, Microcontroller, irrigation, solar energy, Water conservation, energy conservation***

I. INTRODUCTION

Agriculture plays a pivotal role in the Republic of India, analogous to the importance of oxygen to human beings. It not only forms the economic backbone of the nation but also drives individual livelihoods and sustains our populace. A substantial 58% of our population is directly dependent on agriculture for employment. However, despite concerted efforts, including the Green Revolution, the agricultural sector's contribution to India's GDP remains remarkably low, standing at a mere 17% of the total economy. This discrepancy is primarily attributable to the suboptimal yield of agricultural produce in the country.

One critical factor influencing agricultural growth is irrigation. India's agricultural sector's diminished contribution to GDP and the substantial dependence of its populace on this sector translate to low per capita income levels. Consequently, irrigation practices often involve excessive watering, with fields sometimes being inundated for extended periods or irrigated unnecessarily. Moreover, the unpredictable nature of rainfall occasionally results in farmers irrigating their fields just before a rain shower, a seemingly minor issue that can have significant repercussions. Excessive moisture in the soil can lead to soil clogging, impeding the exchange of oxygen and nitrogen gases crucial for plant health and yield.

Addressing these challenges necessitates an affordable solution, which this paper aims to propose. Our objective is to automate the irrigation process by integrating a system that anticipates and adapts to imminent rainfall events. The system continuously monitors soil temperature and moisture levels, making real-time adjustments to maintain optimal conditions for crop health. Additionally, it incorporates a rainfall prediction feature, which assesses the likelihood of rain in the near future before activating the irrigation pump. This approach ensures that water levels in the fields remain within the desired range, mitigating soil clogging and promoting plant growth.

Of noteworthy significance is the system's reliance on solar-based energy, eliminating the need for fossil fuel consumption and reducing carbon emissions. This eco-friendly attribute not only contributes to environmental sustainability but also ensures the system's continuous operation, regardless of energy availability.

In conclusion, our research endeavors to present a scholarly solution to enhance agricultural productivity in India by automating irrigation processes. By optimizing water management through real-time monitoring and predictive capabilities, our system has the potential to revolutionize Indian agriculture while aligning with environmental sustainability goals.

II. LITERATURE OVERVIEW

The Internet of Things (IoT) represents a convergence of various technological components, including microprocessors, memory devices, input/output peripherals, sensors, and actuators, all interconnected to facilitate the exchange of information. Contrary to its name, IoT does not exclusively rely on the internet for connectivity; it can function within any network capable of transmitting data.

In this section, we delve into prior research and systems, examining their methodologies and outcomes. Arunava Chaterjee and Soumyajit[VI] Ghosh proposed a novel approach employing photovoltaic (PV) modules to power essential components like storage batteries, water pumps, soil moisture sensors, and DC motor-based pumps. Their system featured an Atmega-based controller, and its operation was contingent on solar radiation levels and soil moisture content. Significantly, the emphasis lay on energy efficiency through the use of PV motors.

Prachi Subhash Kulkarni and Jitendra Pajendra[VII] introduced a system centered around continuous soil moisture monitoring using moisture sensors. When the soil's moisture level dipped below a certain threshold, a relay triggered the activation of a water pump, harnessing available energy resources. Their primary focus resided in the automation of irrigation systems, optimizing water usage.

HGCR Laksiri, HAC Dharmagunawardhana, and JV Wijayakulscreriya[II] undertook the development of a machine learning platform employing neural networks for weather forecasting and crop irrigation management. Sensors measuring moisture, humidity, and temperature provided input data, which was then transmitted to a local processing unit, a wireless communication module, and ultimately to a cloud server. Here, machine learning models processed and analyzed the data, which was subsequently relayed through a web application to end-users. These users had the autonomy to decide whether to activate irrigation pumps, thereby controlling water levels in their fields, based on the insights provided by the system.

Yan Zhao, Yong Long Yu, Jun Kang, and Aong Chey Zhag[III] introduced an IoT architecture featuring a collection and control layer, which incorporated NB-IOT sensors, PLC-controlled pumps, PH sensors, electric ball valves, and other irrigation equipment. The network transmission layer was responsible for uploading sensor data to the cloud via NB-IOT. Subsequently, data underwent computation and analysis in the terminal application layer before being stored in a database and sent back to the PLC through DTU for precise irrigation adjustments. This system offered continuous access to historical and real-time data, utilizing graphical representations to highlight patterns and changes.

A proposed autonomous irrigation and monitoring system by Vaishali S, Suraj S, Vignesh S, Divya S, and Udayakumar[V] featured a Raspberry Pi, water pump, and various sensors for moisture and temperature monitoring. Communication was facilitated through mobile phones. This system exhibited an intricate understanding of crop or plant water requirements at various growth stages, enabling the precise management of water resources.

In summary, these previously explored systems and methodologies present diverse approaches to address the challenges of efficient irrigation and agriculture management through IoT. They underscore the importance of automation, energy efficiency, data analysis, and user control in optimizing crop yield, conserving water resources, and ultimately contributing to the sustainability of agriculture.

III. PROPOSED SYSTEM

COMPONENTS REQUIRED FOR OUR SYSTEM

MICROCONTROLLER

We employ the NODEMCU ESP8266 microcontroller for our operations. This versatile device can be programmed using the Arduino IDE and is equipped with WiFi ESP8266, enabling seamless connectivity to wireless networks. It boasts compatibility with both analog and digital devices through its Analog (A0) and Digital (D0-D7) pins, facilitating a wide range of interfacing possibilities. Additionally, it supports serial communication, allowing connections to serial devices such as LCD displays, accelerometers, gyroscopes, touch screens, and more, making it a versatile and essential component for our projects.

Soil moisture sensor

The soil moisture sensor is a three-pin digital device. Two pins supply power, while the third serves as the output. Using this sensor is straightforward: insert it into the soil, and based on a predefined threshold, it will detect moisture levels and output either HIGH or LOW signals. A HIGH signal corresponds to a 5V potential at the output terminal, while a LOW signal indicates 0V potential.

Solar panel

Solar panels comprise Photovoltaic cells, which have achieved up to a 50% energy conversion rate from solar to electric energy in scientific experiments. However, commercially available solar panels typically exhibit efficiencies ranging from 15% to 20%. In our system, cost constraints, especially for farmers with limited resources, lead us to employ a 15% efficient solar panel. The provided figure illustrates the average solar power generation over a 12-hour duration when the panel receives sunlight, quantified in watts per square meter.

Battery charging and protection

In standalone solar setups, solar regulators, or charge controllers, are essential. They primarily serve to prevent battery overcharging (by disconnecting solar panels when batteries are full) and excessive discharge (by disconnecting loads as needed), optimizing battery efficiency.

Motor

We opt for a DC motor instead of an AC motor in our system to avoid the need for an inverter, which would otherwise increase the system's cost by converting DC to AC power.

Relay

A relay functions as an electrical switch, operating on electromagnetic induction. When the relay circuit detects fault current, it activates an electromagnet, generating a magnetic field. This magnetic force then engages the motor in response to input signals from the microcontroller.

Weather API

Weather APIs are open-source code components seamlessly integrated into various systems, enhancing daily activities. They empower online news sources to deliver local weather updates, enable travel websites to furnish real-time conditions in different destinations, assist home automation systems in optimizing energy consumption through temperature monitoring, and aid smartphone apps in planning outdoor activities based on up-to-the-minute forecasts. These APIs find versatile applications across a spectrum of services, enriching user experiences with timely weather information.

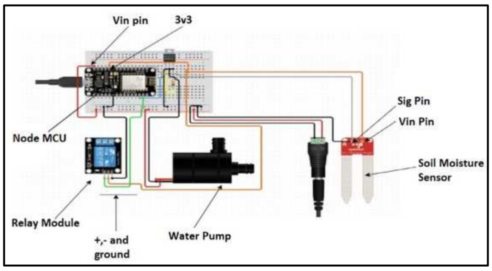


Fig 1 Circuit diagram of smart irrigation system

IV. METHODOLOGY

The proposed system represents a sophisticated approach to efficient and sustainable irrigation, driven by the careful management of resources and data-driven decision-making. Central to this system's operation is the DC pump, a crucial component that ensures crops receive the required moisture for optimal growth. Power for this pump is primarily supplied by a PV (photovoltaic) module, tapping into the abundant energy resource of sunlight. When the PV module generates an excess of power, it directly powers the pump, ensuring a seamless and eco-friendly irrigation process. However, in cases where the PV module's power production falls short of the pump's demands, the system is designed to access stored energy from a connected battery system. This smart power management strategy guarantees uninterrupted irrigation even when solar energy generation is insufficient, contributing to overall system reliability.

The triggering of the DC pump is closely tied to soil moisture levels, monitored continuously by a soil moisture sensor embedded in the ground. When this sensor detects that the soil moisture has dipped below a predefined threshold, it sends a signal to the system's microcontroller, signaling the need for irrigation. The microcontroller, a central decision-making component of the system, subsequently engages with external data sources through a real-time API hosted on a cloud server. This external data primarily consists of meteorological information, offering precise weather forecasts for the system's operational area.

The key aim of this data retrieval is to ascertain whether there is an imminent precipitation event, specifically during the next anticipated interval. This step is pivotal in avoiding unnecessary irrigation when natural rainfall is anticipated. If the API indicates impending rain, the microcontroller prudently decides not to activate the DC pump, allowing nature to fulfill its role in watering the fields. This strategic decision prevents over-irrigation, which can lead to waterlogging and soil degradation, conserving both water resources and energy.

However, in scenarios where the weather forecast does not predict rainfall in the immediate future, the microcontroller proceeds to activate a relay, in turn starting the DC pump. The pump proceeds to irrigate the field until the soil moisture levels reach the predetermined upper threshold. These threshold values for soil moisture have been carefully set at a minimum of 60 gm-3 and a maximum of 90 gm-3, striking a balance between efficient irrigation and preventing soil saturation.

U_{th} is the threshold value for the moisture, SoC(t) is the State of charge of battery, I(0) is the initial charge, i(t) is the current going to the battery (either +ve, -ve or 0) , P_{PV} is the power supplied by the pump, P_{Pump} is the power consumed by the pump, M_{cont} is the moisture content of the of the soil in real time, P_{batt} is the power of battery, where negative state indicated charging and positive indicates supply, P is the precipitation in the area, t is the time of the current state.

$$Soc(t) = \int_{o}^{t} i(t)dt + I(0)$$

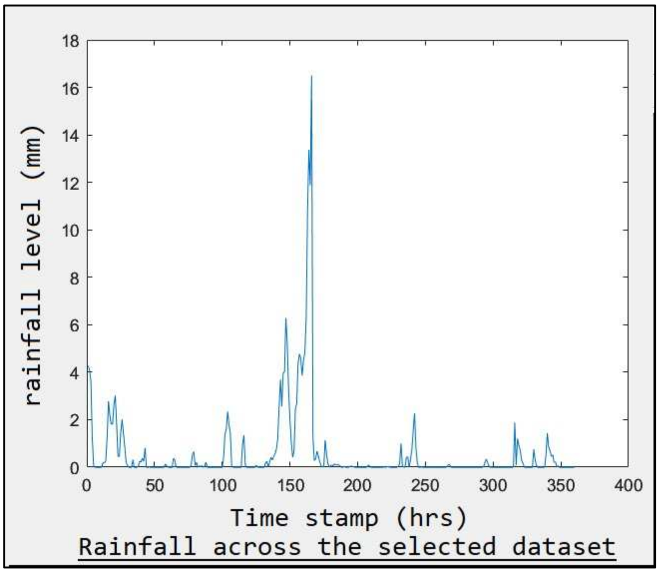


Fig 2: Rainfall across the selected dataset

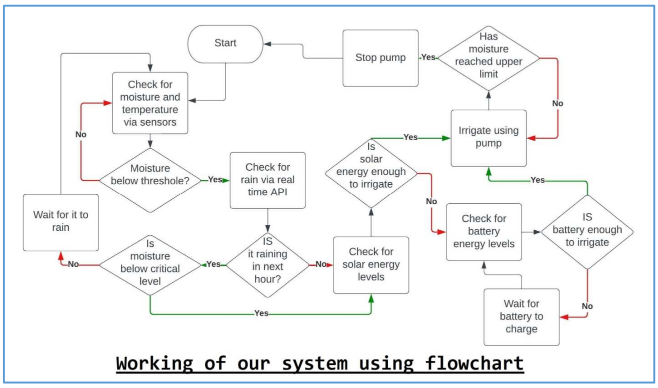


Fig 3: Working of our system using flowchart

Table 1: working conditions of system

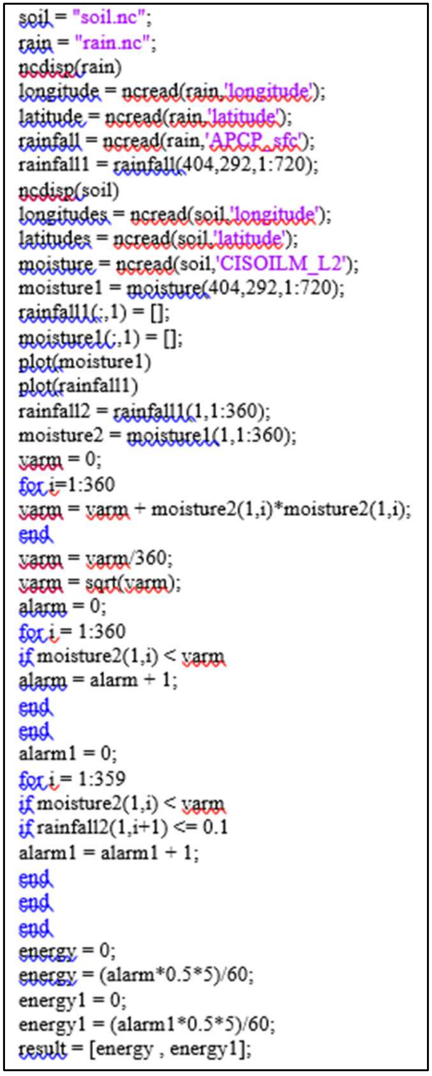
Case 1	$M_{cont}>U_{th}$	P = Not needed to be checked	Soc(t) = 1	$P_{Pump} = 0$	No circulation of power
Case 2	$M_{cont}>U_{th}$	P = Not needed to be checked	Soc(t) < 1	$P_{Pump} = 0$	PV module charges battery
Case 3	$M_{cont}<U_{th}$	P > 0 in next 1 hour	Soc(t) = 1	$P_{Pump} = 0$	No circulation of power
Case 4	$M_{cont}<U_{th}$	P > 0 in next 1 hour	Soc(t) < 1	$P_{Pump} = 0$	PV module charges battery
Case 5	$M_{cont}<U_{th}$	P = 0 in next 1 hour	Soc(t) = 1	$P_{pv}>P_{pump}$	Solar panel powers pump
Case 6	$M_{cont}<U_{th}$	P = 0 in next 1 hour	Soc(t) < 1	$P_{pv}>P_{pump}$	Solar panel powers pump and charges battery
Case 7	$M_{cont}<U_{th}$	P = 0 in next 1 hour	Soc(t) = 1	$P_{pv}<P_{pump}$	Battery powers pump
Case 8	$M_{cont}<U_{th}$	P = 0 in next 1 hour	Soc(t) < 1	$P_{pv}<P_{pump}$	Battery power pump and Solar panel charges battery

Simulation for energy conservation due to rainfall check

The proposed system is simulated using MATLAB (Developed by Mathworks primarily for mathematical computing but with addition of simulink, it can also work on graphical multi domain simulation), we sourced our datasets from open sources such as National solar radiation database (NSRDB)(.gov) and National center for medium range weather forecasting, a national agency for weather forecasting under ministry of earth science,Government of India. We primarily sources total precipitation over the month of June and soil moisture over layer 1(0-0.1m) and soil moisture over layer 2(0.1-0.35m) below ground. We chose 30º N, 75.36º E as the location whose dataset we picked to run our simulation .We calculated energy consumption for two systems; in the first system the irrigation system will be triggered automatically as soon as the moisture in the layer one and layer two heads below the threshold, on the flip side in the second system the system would trigger the pump when the soil moisture level would go below the threshold and it is not going to rain the next clock cycle of the soil moisture check system

V. RESULTS

We ran two simulations for the given data set and found that with precipitation check for this particular data set i.e. june 2014, 30ºN 75.36ºE electricity consumed was 30% less as compared to irrigation without rain check.



```
soil = "soil.nc";
rain = "rain.nc";
ncdisp(rain)
longitude = ncread(rain,'longitude');
latitude = ncread(rain,'latitude');
rainfall = ncread(rain,'APCP_sfc');
rainfall1 = rainfall(404,292,1:720);
ncdisp(soil)
longitudes = ncread(soil,'longitude');
latitudes = ncread(soil,'latitude');
moisture = ncread(soil,'CISOILM_L2');
moisture1 = moisture(404,292,1:720);
rainfall1(:,1) = [];
moisture1(:,1) = [];
plot(moisture1)
plot(rainfall1)
rainfall2 = rainfall1(1,1:360);
moisture2 = moisture1(1,1:360);
varm = 0;
for i=1:360
varm = varm + moisture2(1,i)*moisture2(1,i);
end
varm = varm/360;
varm = sqrt(varm);
alarm = 0;
for i = 1:360
if moisture2(1,i) < varm
alarm = alarm + 1;
end
end
alarm1 = 0;
for i = 1:359
if moisture2(1,i) < varm
if rainfall2(1,i+1) <= 0.1
alarm1 = alarm1 + 1;
end
end
end
energy = 0;
energy = (alarm*0.5*5)/60;
energy1 = 0;
energy1 = (alarm1*0.5*5)/60;
result = [energy , energy1];
```

Fig 4: Code used for simulation of our circuit

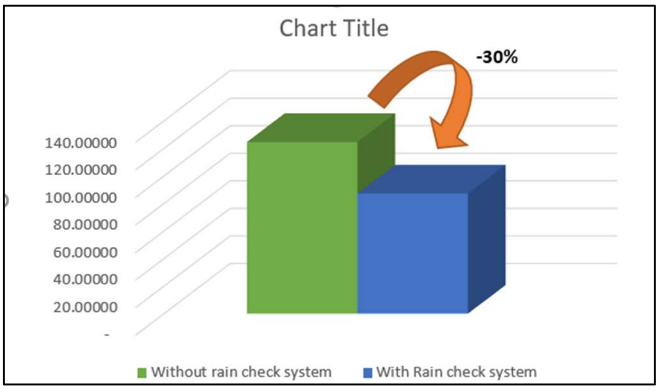


FIG 5: COMPARISON OF CONSUMPTION OF ELECTRICITY

ESTIMATION OF SAVING OF DIESEL COST

Since we replaced diesel energy system with solar energy system, we save a significant amount of Diesel. Using estimation technique and data of energy consumed over 15 days, we interpolate the amount of energy consumed during a year. Using general thumb of rule of 0.4L of Diesel consumed for every Kwh of energy consumed we calculate the amount of diesel and cost of diesel conserved by one farmer. Considering 70% irrigation using groundwater and one pump for every 5 farming families and a nuclear family of four we calculate the annual amount of Diesel and cost of Diesel Saved too. Assuming 1.2$ per Litre Cost of Diesel [Mumbai, India, March 2023].

Table 2: Guesstimation for saving of diesel

Energy consumed during 15 days	5.12 Kwh
Energy consumed during 1 year	123 Kwh
Diesel consumed for producing energy	49.2 L
Population dependent on farming	810 Million
No of families involved in farming	200 Million
No of diesel pumps required for farming	35 million
Amount of diesel saved using our system	1.72 Billion Liters
cost of diesel saved	2.06 Billion Dollars

Estimation of saving of ground water

Our system used 30% less ground water during our estimation period of June 2014. Now estimating two crop cycles and an estimate of 900 Liters of water per Kg of food[X] crop required for each crop cycle we estimate the conserved ground water. Assuming 342 million tons of food produced during a year we calculate estimated amount of ground water saved.

Table 3: Guesstimation on amount of water conserved

Water required per ton of food procures	900,000 Liters
Food produced during 2022 India	342 Million tons
Water required for producing the food	308 Trillion Liters
Water Sourced from groundwater (70%)	215 Trillion Liters
Our prediction system conserved (30%)	64.7 Trillion Liters

VI. CONCLUSION

The paper presents a study whose primary energy source is PV module which is already a renewable source. We used NODEMCU for as a microcontroller for the system and with the addition of precipitation check we were able to save 30% energy for our defined data set in the simulation. IF our system replaced all diesel Pumps In India we can save 2 Billion dollars in cost. Our system if implemented in India can save upto 64.7 trillion Liters of water. This proves that we can save energy and at the same time prevent water logging in the field which also yields in better health of the plantation. This proves that we can save energy and at the same time prevent water logging in the field which also yields in better health of the plantation

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