FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 7 No. 6, December, 2023, pp 192 - 199
DOI: https://doi.org/10.33003/fjs-2023-0706-2056

IOT BASED SOLAR POWERED PUMP FOR AGRICULTURAL IRRIGATION AND CONTROL SYSTEM

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ABSTRACT

This paper focuses on the implementation of a solar-powered pump system integrated with IoT technology for agricultural irrigation control. By leveraging the properties of the system, such as humidity, temperature, soil moisture, time collection based on solar panel activity, and peculiarities like using a mobile app and automated control, the project aims to provide an efficient and sustainable solution for irrigation.The system utilizes humidity sensors strategically placed in the soil to monitor moisture levels, enabling precise irrigation control. To enhance user experience and accessibility, a user-friendly mobile app is developed. This app allows farmers to remotely monitor and control the irrigation process, providing real-time data, irrigation scheduling options, and the ability to adjust system settings. Through IoT integration, the system enables automated control of the pump based on predefined parameters. By analyzing sensor data, including humidity levels and solar panel activity, the system autonomously adjusts irrigation operations, reducing manual intervention and improving overall efficiency. From the acquired results, at a temperature of 37.2 ^{0}C, the humidity level is low at 49.6%, thereby activating the irrigation pump which resulted to decrease in temperature at 26.7^{0}C after a period of 1hr 48mins with the humidity, and soil moisture levels at 73.9%, and 88% respectively. The developed system monitors and balance the soil moisture level through automated irrigation process which is solar powered and remotely managed.

Keywords: Internet of Things (IOT), Irrigation Control, Solar Power, Humidity

INTRODUCTION

Nigeria is the most populated country in Africa, 70% of Nigerians engage in crop farming (Njoku, 2000) . Apart from Oil and Minerals, Agriculture amounts for a large amount of Nigeria's foreign exchange (Central Bank of Nigeria, 2021). In spite of all this, most of the agricultural practices are still manual which wastes a lot of time and reduces the productivity of the farmers also results in less output (Njoku, 2000). There's a lot of solution that could be proffered to this which could automate their techniques and also make it advanced. In solving this problem, we have to factor in the power supply issue in Nigeria and also the cost of power supply and demand. In some cases in Nigeria, there's loss of power for up to 6 hours. To solve this, renewable energy sources have encouraged in the agricultural system especially irrigation/water pumping (Band and Ingole, 2019). Water pumping is very essential in irrigation process but one of the major issues facing modern farming is air pollution and climate change, fossil fuel and diesel-powered water pumps are not environmentally friendly (Cloutier, 2011). This is due to the fact that using fossil fuels like diesel releases carbon dioxide, which increases the danger of global warming and the greenhouse effect on agriculture (Moore and Bruggen, 2011). The increased growth of agriculture in rural areas is driving up the demand for electricity (Nadarajah and Divagar, 2016). IOT is the connection of items involved with sensors, programs, and some technical activities in order to network and exchange information with devices over the internet (Sharma, 2019). The use of IOT with voltage and current sensors to monitor and measure the solar cell charging voltage, amp from the panel to the battery, and current loading from battery to irrigation is carried out by Chieochun *et al*, (2017). The conventional irrigation systems have been severely hampered by the lack of innovation in the agricultural technological sector, noise pollution, water waste, shortages of fuel, and electricity shortages (Moore and Bruggen, 2011). This also signals the necessity to use renewable energy sources to provide the necessary energy for agricultural activities and apply the use of IOT based smart irrigation system (Subramani *et al*, 2020). Especially for farmers in rural regions, solar energy is one of the most promising substitutes for powering irrigation systems that may be used in agricultural activities to decrease the amount of fossil fuel spent and lower the amount of power used (Brodt *et al*, 2011). In comparison to other renewable energies, it is a more inexpensive option for the future due to its abundance, cost-effectiveness, ease of installation, and efficiency (Maisagalla *et al*, 2020). To create a Photovoltaic (PV) system, the solar panel is connected to a voltage regulator, an inverter, and a battery. The Photovoltaic system is based on semiconductor technology that converts sunlight to electricity. Using photovoltaic as the power source for water pumping is considered as one of the most promising areas for PV application (Ratna and Hong, 2020). PV water pumping systems generally consist of PV array, controller unit, motor, pump and water storage tank. Furthermore, these solar pumping systems are environmentally friendly and require low maintenance with no fuel cost. PV water pumping is gaining importance in recent years due to non-availability of electricity and increase in diesel prices (Jones *et al*, 2016).

For small-scale water pumping needs, photovoltaic power for irrigation is more affordable than conventional energy sources (Shinde and Wandre, 2015). In the future, photovoltaic power will become even more cost-effective due to the ongoing rise in the price of fossil fuels and the decline in the peak watt cost of solar cells brought about by mass production. PV-powered water pumping systems are becoming more and more popular for agriculture and animals in isolated areas with limited access to traditional power (Jones *et al*, 2016).

Related Works

IoT-based solar-powered pumps typically involve the integration of sensors, communication devices, and control systems (Murthy *et al*, 2019). These components enable remote monitoring (Bello, 2023), data collection, and control of the pump system, optimizing its performance and efficiency. An example of a current solar-powered portable water pump integrated with an Internet of Things-based smart irrigation system is presented by Roshaliza and Waheb (2022). The study describes the research activities and methods used, as well as the process of design and implementation. The hardware development made use of a relay board for pump control, well chosen sensors, and a NodeMCU ESP8266 Wi-Fi module as a microcontroller. The Arduino IDE was used to develop software that integrated sensor libraries and established the necessary functionality. Using a data collection interface, real-time monitoring and control were made possible by selecting the Blynk IoT platform as the IoT cloud for data transmission and storage. A thorough flowchart outlining the research activities conducted is provided by the study. Overall, this existing implementation demonstrates the successful integration of solar power, IoT technology (Birkel and Hartmann, 2019), and smart irrigation for improved water management in agricultural settings.

Okomba and Okwor, (2017) explained the use of automatic control and sensors that is controlled by the rain, the automation methodology and logic applied by them was also used in this paper because of its similarity in sensing and microcontroller mechanism.

Hermala *et al,* (2022) explained the use of IOT for monitoring hydroponic house. In this paper, the researchers established solar power as a cheap alternative to powering laboratories in as much as it's capital intensive it's described to be a good bargain. The paper also explains the several considerations to be taken to place before picking an IoT device they should be picked based on range, wireless connectivity, power consumption and memory capacity, Hydroponic process is the growing of plants in tanks for research purposes.

MATERIALS AND METHODS

The processes, approach, techniques, methods used in the implementation of the Solar Powered Pump with IoT for Agricultural Irrigation process is shown in the following phases giving an elaborated description of the methodology.

System Modelling

Figure 1 provides an overview of the IoT-Solar Powered Pump's system architecture. In this system, two 20W solar panels will be exposed to the sun's rays, producing electricity that powers the water pump and DC motor set. Through the use of the solar charge controller, the excess energy will be stored in the 12V battery. The battery that powers the microdiagphram pump is a 12V, 7.5 Ah Panasonic lead-acid battery. When needed, the battery capacity can power the motor for up to three hours during nighttime irrigation operations. Data from the sensors is gathered by the microcontroller and transmitted back to the ESP32 via the Wi-Fi access point. Using the graphical user interface created and designed by the software developer, the farmer will also be able to remotely monitor the farm's environmental parameters, such as moisture, temperature, and humidity, using smartphones that are connected to the Internet. In order to connect the sensors to the ESP32, a 12 volts relay is needed. Additionally, the web app notifies the farmer when the threshold is exceeded.

This system model presents a solar-powered pumping system with IoT integration specifically designed to ease farming activities. The system utilizes components such as a 20W solar panel, solar charge controller, ESP32 microcontroller, 12V pump, 12V to 3V buck converter, resistors, a 12V relay, and a 12V battery.

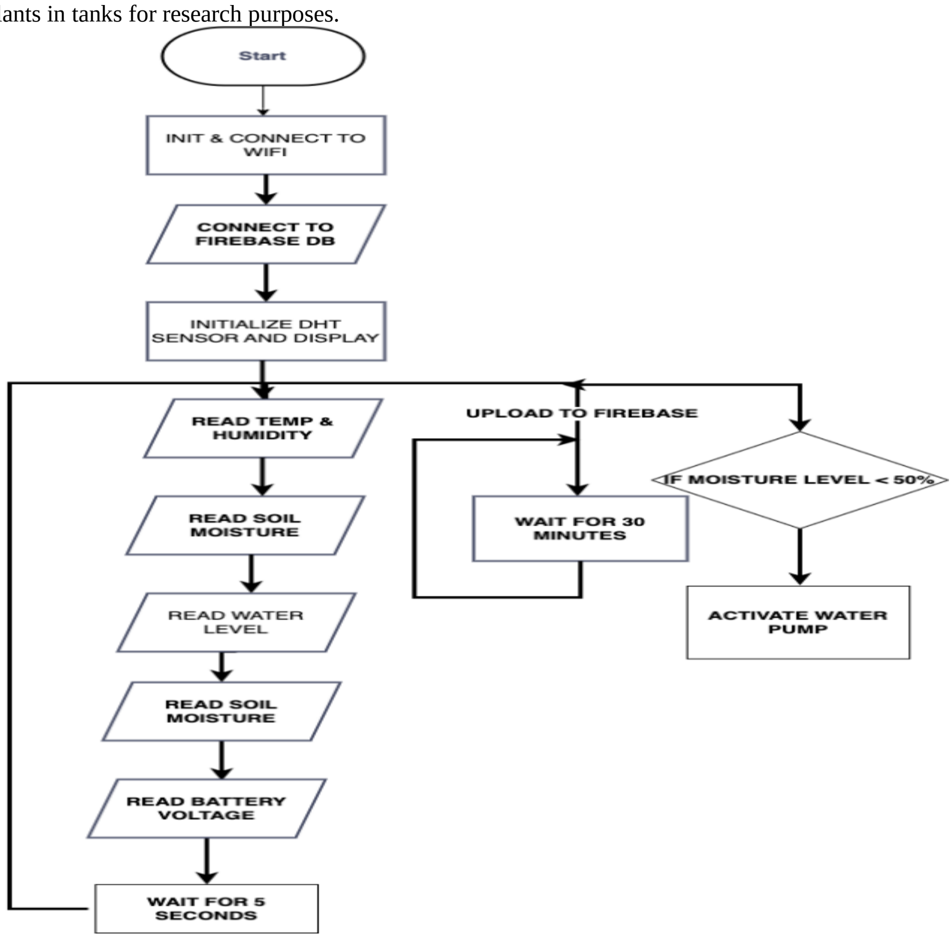

Figure 1: Flowchart of the System

System Design
The solar-powered irrigation system relies on solar panels connected to charge controllers to harness energy from sunlight. This energy charges a battery, and an embedded system manages power distribution through a specialized converter, providing 5 volts for the ESP32 microcontroller and sensors. The ESP32 plays a central role in interfacing with various sensors, including soil moisture and ultrasonic sensors, which monitor soil moisture levels and water tank levels. A voltage divider circuit ensures proper voltage for the ESP32, enabling continuous monitoring of battery status. On the software side, the ESP32 connects to Wi-Fi using stored credentials, stores data in a database, and updates soil moisture readings every 15 seconds. The database data is accessible through a web application, allowing users to control the irrigation pump and maintain optimal soil moisture levels. The system also uses epoch time for accurate time synchronization. Overall, this setup creates an efficient and sustainable irrigation solution.

Software Design and Development
The integration of solar energy and advanced software design is revolutionizing agricultural irrigation, offering efficient resource management and real-time insights for farmers. This innovation combines hardware elements like solar panels, sensors, and actuators with a user-friendly software interface. Data from various sensors, including humidity, temperature, and soil moisture levels, is collected and processed to enable precise irrigation strategies. Farmers can remotely monitor and control the system through a graphical interface, and the software can make smart decisions based on data, such as activating the pump when soil moisture is low. Data analytics capabilities provide historical trends and insights to enhance crop yield. Moreover, the system prioritizes energy-efficiency and sustainability, using solar energy to power the system and reduce its carbon footprint. The provided C++ code snippets lay the foundation for the system's embedded software, including Wi-Fi and Firebase configurations and pin definitions for sensors and actuators.

C++ Code Snippets
```
#include <Arduino.h>
#include <WiFi.h>
#include <Firebase_ESP_Client.h>
#include "time.h"
#include "DHT.h"
#include "addons/TokenHelper.h"
#include "addons/RTDBHelper.h"
#include "oledDisplay.h"
#include "globals.h"
#include <array>
#include <driver/adc.h>
// WiFi credentials
#define WIFI_SSID "your_wifi_ssid"
#define WIFI_PASSWORD "your_wifi_password"
// Firebase API Key and Database URL
#define API_KEY "your_firebase_api_key"
#define DATABASE_URL "your_firebase_database_url"
// Firebase User Credentials
#define USER_EMAIL "user_email"
#define USER_PASSWORD "user_password"
// Pins and configurations
#define DHTPIN 32
#define DHTTYPE DHT11
#define trigPin 33
#define echoPin 25
#define MOISTURE_PIN 35
#define BATTERY_PIN 34
#define PUMP_RELAY 14
#define TANK_DEPTH 28
// Firebase Data object
FirebaseData fbdo;
FirebaseAuth auth;
FirebaseConfig config;
FirebaseJson json;
FirebaseData stream;DHT dht(DHTPIN, DHTTYPE);
// Rest of the code...
void setup() {
  // Rest of the setup code...
}
void loop() {
  // Rest of the loop code...
}
```

Algorithm 1: C++ Code Snippets

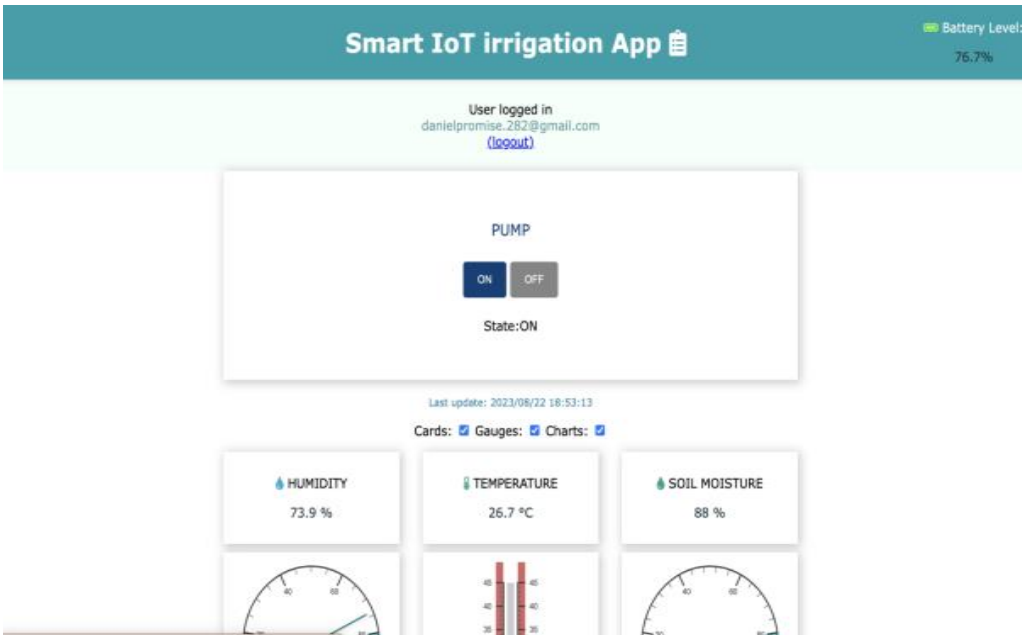

Figure 2: System Graphical User Interface

Components Selection
In the development of this project, a thoughtful selection of components was made to enable advanced functionalities, including soil moisture sensing, data collection, and remote control through the ESP32 microcontroller integrated with Firebase. The ESP32 was chosen for its versatility and built-in Wi-Fi capabilities, allowing real-time data exchange and synchronization with Firebase's robust database. Specialized soil moisture sensors were employed to continuously monitor soil moisture levels, facilitating informed irrigation scheduling and optimizing water usage. A 12V relay controlled the power supply to the irrigation system based on soil moisture readings, eliminating the need for manual intervention. The Integrated Development Environment (IDE) played a pivotal role in programming and development, providing a user-friendly interface and ensuring smooth system operation. This comprehensive selection of components results in a robust and efficient system empowering farmers to monitor, manage, and optimize irrigation processes for improved crop yield and resource conservation.

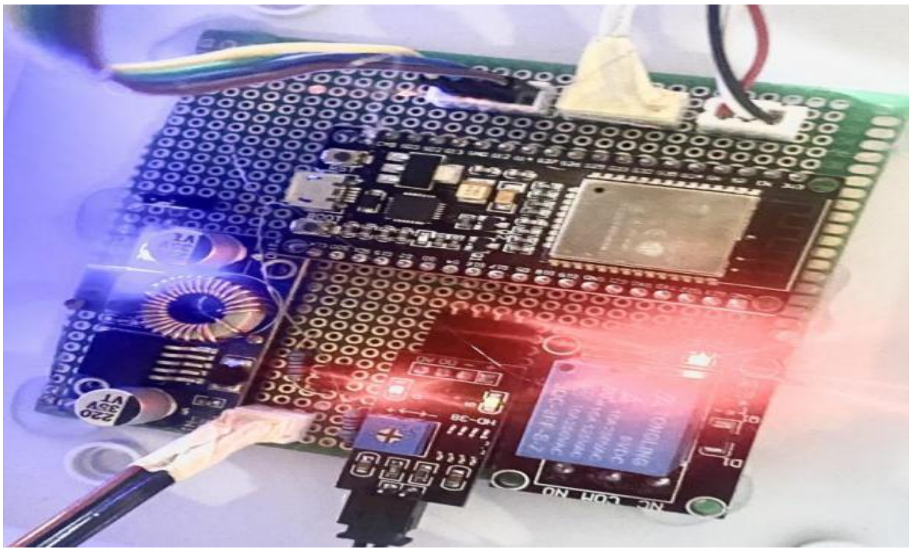
Figure 3: Installation of components in the adaptable box

Circuit Design and Installation
This project comprises both hardware and software components. The hardware portion controls the pump and the solar panel system, which includes photovoltaic cells, while the software portion executes instructions provided by the hardware. The hardware circuit incorporates several components, including the ESP32 Wi-Fi module, a 12V 32A relay, an 1815 transistor, 7805 and 7812 regulator ICs, a 10k resistor, 2200uf and 100uf capacitors, and an IN4007 diode. The circuit design involves converting 230V AC to 12V DC using a rectifier, and then using the 7805 and 7812 voltage regulators to obtain 5V and 12V DC outputs, respectively. Transistors act as switches for the relay, controlled by the 10k resistor for proper biasing. Capacitors filter and regulate the power supply, ensuring stable voltage levels.

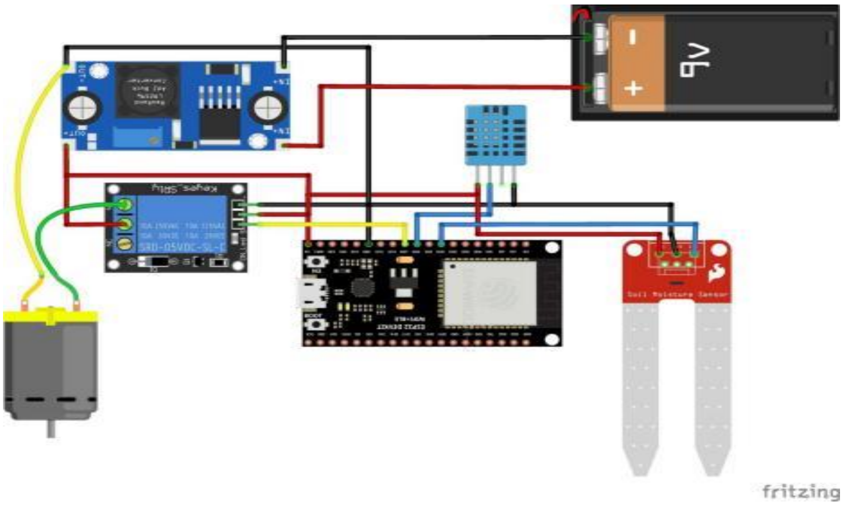

Figure 4: System Circuit Design

The 32A relay is responsible for switching the motor on and off, with the transistors controlling its operation based on the system's requirements. Each component serves a specific function, such as rectification, voltage regulation, switching, and noise filtering, to ensure the proper functioning of the system.

System Operational Procedure

The solar irrigation system represents a remarkable synergy of renewable energy and advanced technology, showcasing the forefront of modern agricultural practices. This intricate system begins with solar panels capturing sunlight and utilizing charge controllers to optimize battery charging. The battery stores this solar energy, while an embedded system efficiently distributes power through a specialized converter to the ESP32 microcontroller and sensors. The ESP32 forms the core of the interface, connecting with crucial sensors like humidity, temperature, and soil moisture sensors, along with an informative OLED-equipped LCD display. The soil moisture sensor intelligently gauges moisture levels by analyzing resistance changes, optimizing irrigation. An ultrasonic sensor monitors water tank levels, and a voltage divider circuit facilitates battery voltage monitoring. This integrated approach promotes sustainable agriculture, resource conservation, and heightened efficiency, showcasing the potential of renewable energy and smart data handling in agricultural technology.

RESULTS AND DISCUSSION

The thorough assessment and analysis of the Solar-Powered Irrigation System with IoT integration (IoT-SIS) following its design and development is the main topic of this section. Strict real-world trials were carried out to evaluate a range of parameters. These experiments included field tests conducted on a real farmland garden, preceded by an initial site visit to gather relevant farm-specific information. The site visit helped assess the farm's characteristics, such as its size, fertigation methods, plant volume, water pumping mechanism, and operational schedule. The tests involved key system components, including solar panels, DC motors, water pumps, and IoT elements, and aimed to verify the system's relevance and adaptability within authentic agricultural settings.

Experimental Setup

The experimental setup involved deploying the solar-powered system at a Small Garden Farm in Ikole Ekiti, located within the Federal University of Oye Ekiti, Ikole Campus. Wi-Fi was used to connect the system to the internet, and a solar-powered DC water pump was integrated into it. The pump's inlet port was primed and connected to a suction pipe to guarantee correct operation. A hose pipe was also used to connect the Fertigation Farm's irrigation system to the solar water pump. Through the use of an ESP32 microcontroller and Firebase database, a custom web application was able to activate the solar water pump. Simultaneously, a humidity sensor was embedded in the soil to monitor moisture levels, while water levels were carefully measured as part of the experimental setup.

Validation experiments were conducted in a real agricultural environment, utilizing a solar-powered irrigation system with key components including a solar panel, DC water pump, advanced humidity and temperature sensors, and an ESP32 microcontroller as the central control unit. These experiments aimed to assess the system's performance and efficiency.

i. Power Consumption Analysis: The study recorded the system's power consumption under varying conditions to evaluate its energy optimization capabilities, emphasizing its role as an environmentally responsible irrigation solution.
ii. Flow Rate Validation: Precise measurements were taken to assess water flow regulation within the irrigation pipeline, providing insights into the system's ability to consistently deliver controlled and uniform water distribution to cultivated areas.
iii. Humidity and Temperature Sensing: DHT11 sensor was used to monitor soil moisture and temperature in real-time. This data was transmitted to the ESP32 microcontroller, enabling dynamic irrigation scheduling based on immediate environmental conditions.
iv. Trigger Time Synchronization: The study scrutinized the system's ability to align sensor inputs with irrigation directives, demonstrating its responsiveness to changing conditions and its capacity for precise irrigation scheduling.

The results of these experiments highlighted the solar-powered irrigation system's effectiveness in terms of energy efficiency, uniform water distribution, intelligent irrigation scheduling, and prompt responsiveness to environmental changes, reinforcing its suitability as a sustainable irrigation solution.

Table 1: Table of Values from Web App

Timestamp	Temp (°C)	Hum (%)	Soil_moist (%)
2023/08/22 18:53:13	26.7	73.9	88
2023/08/22 18:30:21	27.0	96.7	84
2023/08/22 18:20:21	27.4	95.6	84
2023/08/22 18:10:20	28.8	90.9	85
2023/08/22 18:00:20	29.9	86.1	85
2023/08/22 17:50:20	29.9	89.1	90
2023/08/22 17:39:39	29.7	90.9	86
2023/08/22 17:29:38	27.9	97.4	85
2023/08/22 17:19:38	29.1	83.0	92
2023/08/22 17:12:33	32.5	60.1	88
2023/08/22 17:05:31	37.2	49.6	89

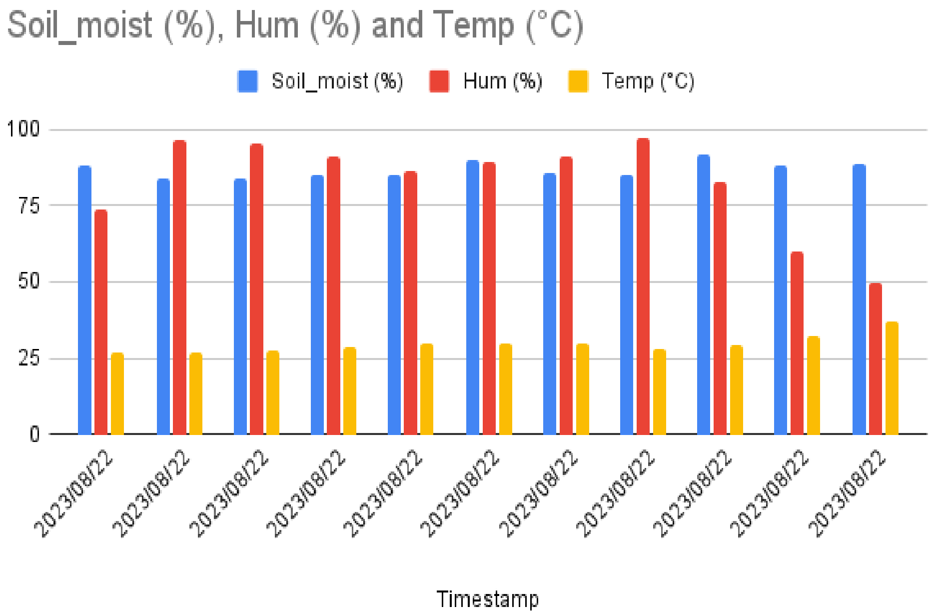

Figure 6: Soil moisture vs Humidity vs Temperature

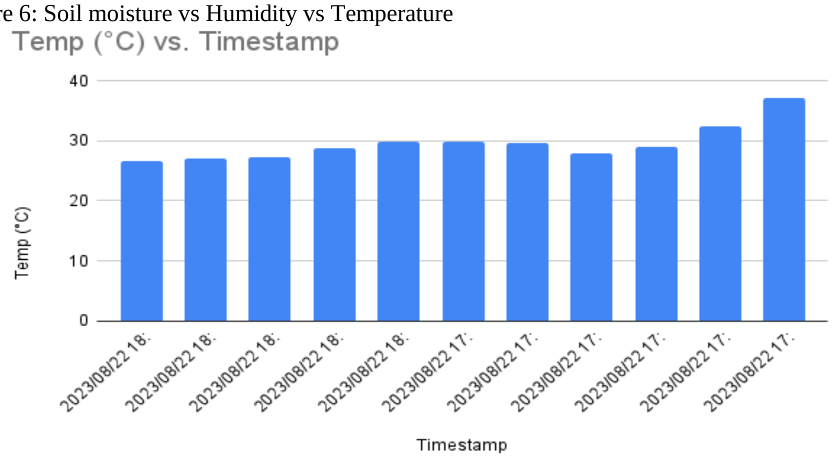

Figure 7: Soil moisture vs Timestamp Graph

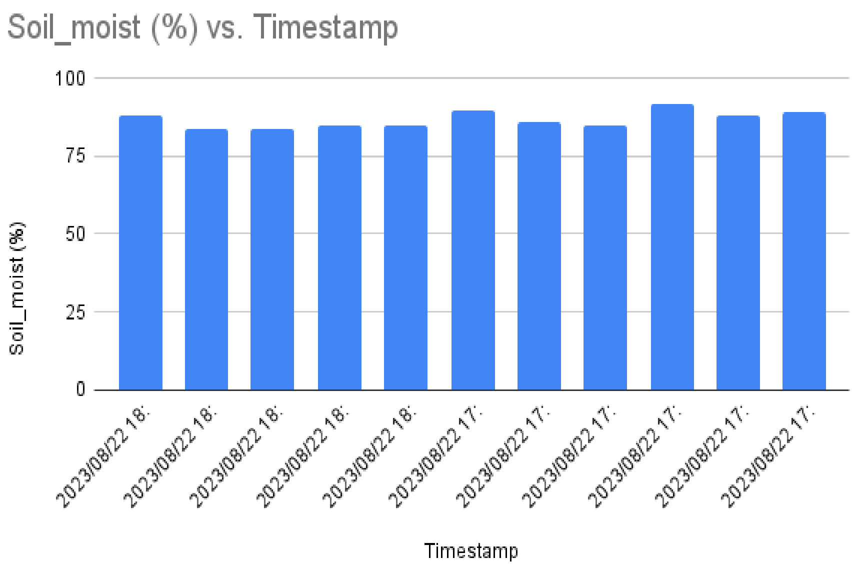

Figure 8: Temperature vs Timestamp Graph

As specified in figures 6, 7, and 8, we could realize the collection of data is done periodically based on an interval set in the codebase of the research, it's also controlled by the humidity of the soil. The battery charging is also controlled by a charge controller that charges it when the battery is low. In the onsite testing the performance of the irrigation system has been observed, measured and evaluated

CONCLUSION

The research on the solar-powered irrigation system with IoT integration and advanced software design concludes with several key findings.

The system demonstrates its efficiency and sustainability by harnessing solar energy, reducing reliance on traditional power sources, and promoting sustainable agriculture by activating the irrigation pump once humidity level is sensed at set values programmed in the controller. Precision irrigation through humidity sensors triggers off water pump once programmed set point is achieved thereby preventing water wastage, especially in water-scarce regions. The user-friendly mobile app enables real-time monitoring and control, enhancing operational convenience. Data-driven decision-making based on sensor data informs irrigation strategies. Automation reduces manual labor and environmental impact while optimized irrigation schedules lead to improved crop yields. The system's scalability and adaptability make it versatile for various agricultural setups. Challenges such as sensor accuracy and connectivity stability must be addressed, and future enhancements may include predictive analytics and machine learning. Overall, this research signifies a significant step towards sustainable farming practices, merging renewable energy, technology, and data-driven strategies to revolutionize agriculture.

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