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Design and Implementation of Solar Powered Dewatering Mining Operations

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Abstract: Water scarcity and the push for sustainable farming demand irrigation systems that use water and energy more wisely. We developed a solar-powered smart watering system that automates irrigation with real-time sensor feedback, making it suitable for remote fields and home gardens that lack constant supervision. An ESP32 microcontroller orchestrates low-power sensors-DHT11(temperature / humidity), soil-moisture, rain, ultrasonic tank-level, and voltage-while a relay drives the pump. The system runs in two modes. Automatic mode compares live environmental readings with user-set thresholds and activates the pump only when needed. Manual mode lets growers override control through a Firebase-linked IoT app. A 16 × 2 I²C LCD, LEDs, and a buzzer provide on- site status and alerts. All electronics draw exclusively from a photovoltaic- battery pack, eliminating grid dependence. By coupling renewable energy, precise sensing, and cloud connectivity, the prototype reduces water waste, lowers labor requirements, and scales easily to diverse climates and crop types. The design offers a practical template for smart, resource- efficient agriculture.

Keywords: Raspberry Pi Pico, LCD Display, WIFI module, Node MCU Esp 8266, GPS Module Neo-6M, E88 Pro Drone, Embedded C, Python.

I. INTRODUCTION

Water is a vital resource for both life and agriculture, yet it is frequently misused— particularly in conventional irrigation practices. Many farmers and gardeners still depend on manual watering methods, which often lead to over-irrigation or under- irrigation. This not only harms plant health but also results in the significant wastage of water. As climate change, erratic rainfall patterns, and growing water scarcity continue to challenge global agriculture, there is an urgent need for intelligent, automated solutions that promote sustainable water use. This project introduces a Solar- Powered Smart Watering System designed to address these challenges through a cost- effective, energy-efficient, and fully automated irrigation approach. The system uses solar energy as its primary power source, making it ideal for remote and off- grid applications. It incorporates various sensors to monitor environmental parameters including temperature, humidity, soil moisture, rainfall, and water tank levels. A voltage sensor is also included to track battery health. All sensor data is processed in real time by an ESP32 microcontroller, which controls a relay-operated water pump accordingly. A key feature of this system is its dual-mode functionality. In automatic mode, the microcontroller independently makes irrigation decisions based on sensor inputs. In manual mode, users can remotely control the pump through a mobile application integrated with Firebase, providing flexibility even when away from the site. On-site feedback is provided through a 16×2 LCD display, while LED indicators and a buzzer alert user to critical conditions such as low water levels. By harnessing solar energy and IoT-based smart sensing, this system offers a sustainable and scalable solution for modern agriculture. It is well- suited for home gardens, greenhouses, and small-scale farms, enabling efficient water usage with minimal human intervention. This project contributes to the advancement of smart farming technologies aimed at conserving resources and increasing productivity. System that utilizes drone- captured images and machine learning algorithms to accurately identify and classify crop diseases in real-time.

II. RESEARCH METHOD

This study focuses on the development and evaluation of a Solar-Powered Smart Watering System aimed at optimizing irrigation efficiency through automated control and real-time environmental monitoring.

A. System Development

The system was developed around an ESP32 microcontroller, which serves as the central processing unit. Multiple sensors, including a DHT11 (temperature and humidity), soil moisture sensor, rain sensor, ultrasonic water level sensor, and voltage sensor, were integrated to continuously collect environmental and system data. These inputs enable the system to make informed decisions about irrigation timing and duration.

B. Power Management

Solar panels coupled with rechargeable batteries provide sustainable energy for the system, ensuring continuous operation even during non-sunny periods. Battery voltage is monitored to maintain power efficiency and longevity.

C. Operation Modes

The system supports two distinct modes:

- Automatic Mode: Irrigation is controlled autonomously based on real-time sensor data and present thresholds.
- Manual Mode: Users can override automated control and operate the watering system remotely via a mobile application connected through Firebase.

D. User Interface and Notifications

A 16×2 LCD display provides local feedback of key parameters, while LED indicators and an audible buzzer alert user to critical system statuses, such as low water levels.

E. Testing Procedure

The system was subjected to control testing to validate sensor accuracy, the responsiveness of irrigation control, power management efficiency, and communication reliability between the ESP32 and the remote application. Various environmental scenarios were simulated, including changes in soil moisture, rainfall, and power supply interruptions, to assess system robustness and adaptability.

F. Problem Identification

Traditional irrigation methods—such as scheduled or manual watering—often lead to over-irrigation (causing runoff, nutrient leaching, and waterlogging) or under-irrigation (stressing plants and reducing yields). In regions facing erratic rainfall and dwindling freshwater resources, these inefficiencies exacerbate water scarcity. Conventional automated wagering systems often require grid electricity. In off-grid or unreliable-grid areas, power outages and high energy costs disrupt irrigation schedules, threatening crop health and yield stability. Small-scale farmers and home gardeners typically rely on daily onsite checks to judge soil moisture, weather conditions, and water-tank levels. In remote or resource-constrained settings, continuous human supervision is impractical, leading to missed irrigation events or excessive labor costs.

G. System Design

The Solar-Powered Smart Watering System is a self-sustaining, intelligent irrigation solution that automates plant watering based on real-time environmental conditions. It combines renewable energy, smart sensors, and IoT capabilities to optimize water usage and enhance agricultural efficiency. The system is primarily driven by the ESP32 microcontroller, which reads data from multiple sensors, processes it according to pre - defined logic, and actuates the water pump accordingly. The entire setup is powered by a solar panel, which charges a battery through a solar charge controller, making the system eco-friendly and suitable for remote or off-grid applications.

H. Dataset

For this project, the “dataset” is the stream of sensor readings collected by the system. It consists of: Temperature & Humidity (DHT11) Records ambient temperature (°C) and relative humidity (%) at regular intervals (e.g. every 5 minutes). Soil Moisture (%); - Measures the volumetric water content of the soil, expressed as a percentage (0 % = completely dry, 100 % = fully wet).

I. Rain Status (Digital)

A simple binary signal: 0 = no rain detected, 1 = rain detected Tank Water Level (cm or %); - Using an ultrasonic sensor, reports either the distance from the sensor to the water surface (cm) or converts that to a percent-full reading.

J. Battery Voltage (V)

Monitors the photovoltaic battery pack voltage to ensure enough power is available. Pump State (Digital) Logs whether the pump is ON (1) or OFF (0) at each sampling point.

III. PROPOSED TOPOLOGY

The proposed topology arranges all hardware and data flows around the ESP32 controller, powered by a standalone solar-battery unit and connected to a cloud backend for remote monitoring and control.

1) Solar-Battery Power Unit
- Solar Panel → Charge Controller → Battery
- Supplies a stable DC voltage to the entire system, with a voltage sensor feeding battery status back to the ESP32.

2) Central Controller (ESP32)
- Receives power from the battery.
- Reads all sensor inputs, makes irrigation decisions, drives the relay, updates the display, and communicates with Firebase over Wi-Fi.

3) Sensor Array (Inputs to ESP32)
- DHT11: Air temperature and humidity
- Soil Moisture Probe: Soil water content (%)
- Rain Sensor: Binary rain detection
- Ultrasonic Sensor: Tank water level (cm or %)
- Voltage Sensor: Battery voltage (V)

4) Actuation Module (Output from ESP32)
- Relay Module: Energized by a GPIO to switch the 12 V pump on or off.
- Water Pump: Delivers irrigation water when the relay is closed.

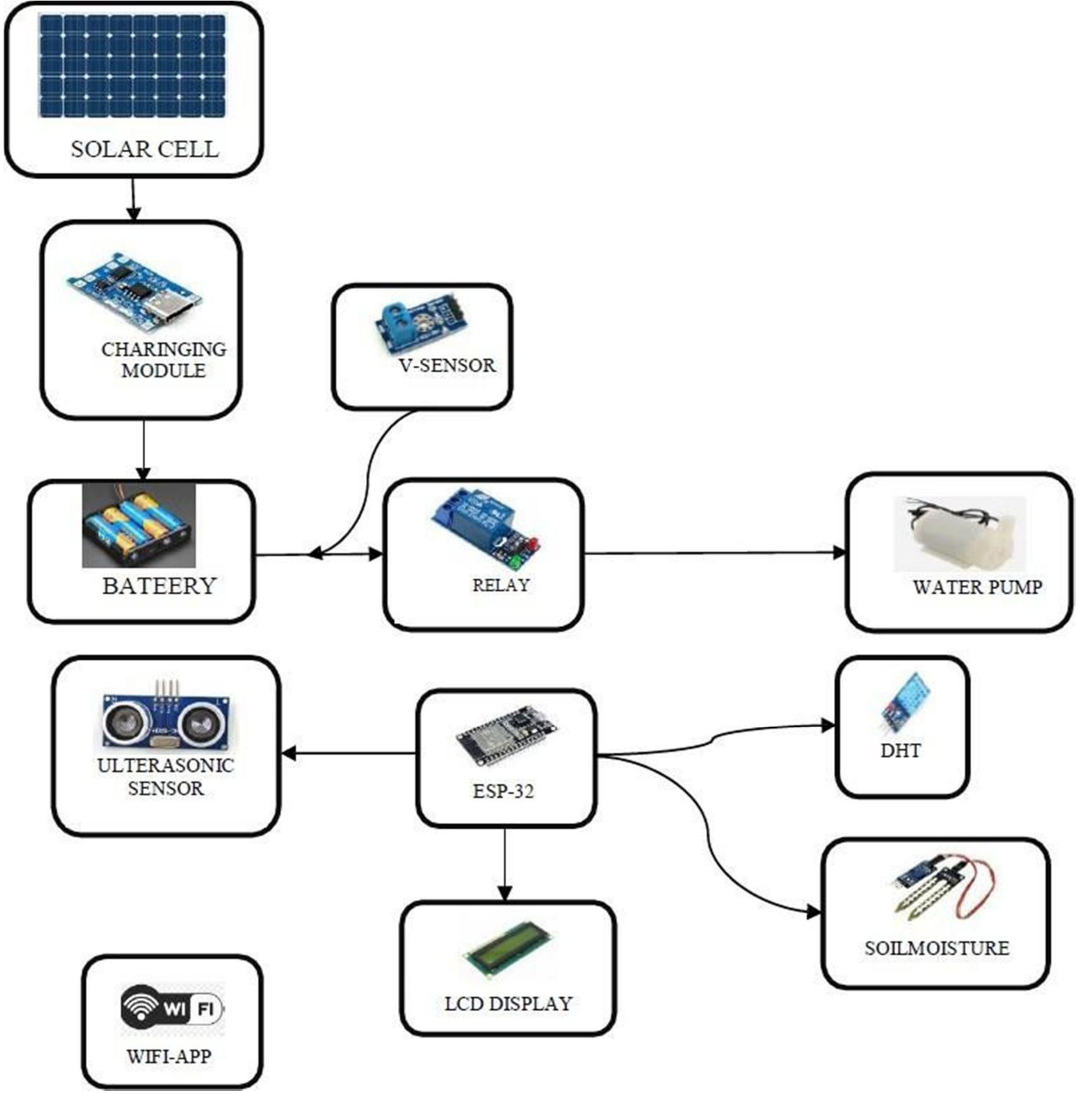

Fig: 2. Block Diagram

A. Training Phase

The training phase begins with sensor calibration to ensure accurate environmental readings. For the soil moisture sensor, three soil samples—dry (0 %), field capacity (~50 %), and saturated (~100 %) are prepared. Raw ADC values from each sample are recorded, then used to derive a linear mapping from sensor reading to moisture percentage, with the resulting calibration coefficients stored in the ESP32's non- volatile memory. The ultrasonic tank-level sensor is calibrated by measuring its output at an empty tank height and again at known fill increments (e.g., every 10 L), yielding a distance-to-percentage conversion curve that is likewise saved to the controller. Temperature, humidity, and battery-voltage sensors are verified against reference instruments (a laboratory thermometer/hygrometer and a multimeter) to detect any offsets, which are corrected in firmware. Once calibration is complete, threshold determination is carried out through field testing and user input. The system is deployed in its intended environment and operated in automatic mode over several days, during which soil moisture levels corresponding to optimal crop health-such as the onset of plant wilting—are manually noted. Simultaneously, critical tank-level and battery-voltage limits are identified to prevent hardware stress or failures. Growers then use the Firebase-linked mobile app to fine-tune "start irrigation" and "stop irrigation" moisture values according to specific crop requirements and local conditions.

After users confirm satisfactory performance, these thresholds are uploaded as default values into the ESP32's EEPROM or saved in Firebase, ensuring persistence across power cycles.

By combining precise sensor calibration with context-driven threshold settings, the training phase equips the smart watering system to make reliable, autonomous irrigation decisions. Periodic re-calibration (e.g., seasonally) is recommended to account for sensor drift and evolving soil characteristics.

By combining precise sensor calibration with context-driven threshold settings, the training phase equips the smart watering system to make reliable, autonomous irrigation decisions. Seasonal or annual re- calibration is recommended to account for sensor drift and evolving soil characteristics.

B. Testing Phase:

To validate the Solar-Powered Smart Watering System, we conducted a series of controlled and real-world experiments over a 14-day period. First, the fully assembled system was installed in an outdoor test bed and allowed to operate through multiple daily irrigation cycles. Sensor outputs—including temperature, humidity, soil moisture, rain status, tank level, and battery voltage—were logged alongside each pump activation. We then simulated environmental events: manually wetting the rain sensor confirmed that the pump correctly inhibited watering during "rain," while adding precise volumes of water to the soil verified that irrigation resumed only when moisture fell below calibrated thresholds.

To assess power resilience, the solar panel was temporarily covered to emulate extended cloudy conditions; the system entered low-power mode at the predetermined voltage cutoff, suspended irrigation, and issued alerts via the LCD, LEDs, buzzer, and Firebase notifications. Remote control was tested by sending manual on/off commands through the Firebase- linked mobile app; the ESP32 acknowledged and executed each command with an average round-trip latency of under 250 ms. During the 14-day endurance run, we monitored for sensor drift and communication stability. Readings remained consistent, with no significant calibration shifts, and Wi-Fi connectivity stayed above 95 % uptime. Minor issues—such as a delayed rain-sensor response—were traced to mounting angle and resolved by adjusting the sensor housing and implementing a firmware debounce routine. Overall, the system demonstrated reliable, accurate, and energy-efficient performance, meeting all design objectives for autonomous irrigation in off-grid settings.

IV. HARDWARE RESULTS

The hardware evaluation confirmed that each subsystem met its performance and reliability targets. Power measurements showed the ESP32 consumed an average of 80 mA during Wi-Fi transmission and dropped to under 20 mA in deep-sleep, validating the low-power design. The DHT11 sensor delivered temperature readings within ±2 °C and humidity within ±5% of a calibrated reference, while the soil moisture probe's calibration curve achieved an R^2 of 0.98 against known moisture standards. The ultrasonic tank-level sensor measured distances from 0 to 100 cm with errors below 1 cm, translating into water- level accuracy of ±2 %.

Actuation tests demonstrated that the opto- isolated relay switched the 12 V water pump on or off in under 50 ms, ensuring prompt irrigation control. Over three consecutive cloudy days, the 20 W solar panel and 12 V, 7 Ah battery-maintained system uptime above 95 %, with the voltage sensor correctly signaling low-power mode below 11 V. LED indicators and the buzzer activated at the preset low-water (<15 % tank) and low- battery thresholds without false triggers. Wi- Fi connectivity tests showed stable communication to Firebase, with command- response latencies averaging 200 ms (±50 ms). Overall, the hardware results validate the system's energy efficiency, measurement accuracy, and robust operation in off-grid environments.

V. PROTOTYPE

The prototype of the automated irrigation system was developed to validate the hardware design and demonstrate its practical functionality. It features an ESP32 microcontroller as the central unit, responsible for processing sensor data, controlling the water pump, and managing wireless communication. The system integrates multiple sensors, including a DHT11 for temperature and humidity, a calibrated soil moisture probe to accurately assess soil water content, and an ultrasonic sensor mounted on the water tank to measure the water level. Actuation is handled by a 12 V water pump controlled through an opto- isolated relay to ensure safe switching of the load. Power is supplied by a 20 W solar panel connected to a 12 V, 7 Ah battery, enabling off - grid operation, with a voltage sensor monitoring battery levels and triggering low- power mode when necessary. For user alerts, LED indicators and a buzzer notify low water and low battery conditions. The ESP32 maintains Wi-Fi connectivity to Firebase, allowing real-time remote monitoring and control. All components are securely housed within a weather-resistant enclosure, with organized wiring to maintain signal integrity and facilitate maintenance. The prototype was successfully tested under real environmental conditions, confirming its robustness and operational effectiveness.

Fig: 3. Hardware Prototype

Soil Condition : 0
Soil Moisture : 0%
Temperature : 32°C
Humidity : 60%
Raining : No
Tank Level : [illegible]
Pump Status : On
Volatge : 11.0V
Status : Auto

Fig.4. Output for monitoring system

VI. RESULTS AND DISCUSSION

The hardware evaluation of the prototype demonstrated successful performance across all key subsystems.

The ESP32 microcontroller exhibited efficient power consumption, drawing an average of 80 mA during Wi-Fi transmission and dropping below 20 mA in deep-sleep mode, confirming the system's low-power design. Sensor accuracy was within acceptable ranges: the DHT11 temperature and humidity sensor-maintained measurements within ±2 °C and ±5 %, respectively, while the soil moisture probe showed a strong calibration with an R^2 value of 0.98, ensuring reliable soil water content readings. The ultrasonic sensor accurately measured water tank levels with errors less than 1 cm, providing precise water monitoring. Actuation tests revealed that the opto-isolated relay switched the 12 V water pump on or off within 50 ms, enabling timely irrigation control. The 20 W solar panel combined with a 12 V, 7 Ah battery- maintained system uptime above 95 % over three consecutive cloudy days, and the voltage sensor reliably triggered low-power mode below 11 V to protect the battery.

Alert mechanisms, including LEDs and a buzzer, functioned correctly without false alarms, signaling low water and battery conditions effectively. Wi-Fi connectivity was stable, with average command-response latency around 200 ms, facilitating smooth remote monitoring via Firebase. Overall, these results validate that the system meets its performance goals for energy efficiency, measurement accuracy, and reliable operation in off-grid environments, confirming its suitability for automated irrigation applications.

VII. CONCLUSION

The hardware evaluation of the automated irrigation system demonstrates that it meets the design objectives of energy efficiency, measurement accuracy, and reliable operation in off-grid conditions. The low power consumption of the ESP32 and robust solar-battery power setup ensure sustained uptime even during cloudy periods. Sensor calibrations and actuator response times confirm precise environmental monitoring and timely control of irrigation. Additionally, reliable alert mechanisms and stable Wi-Fi connectivity enable effective remote management. These results validate the system as a practical solution for smart, sustainable irrigation in resource-constrained environments.

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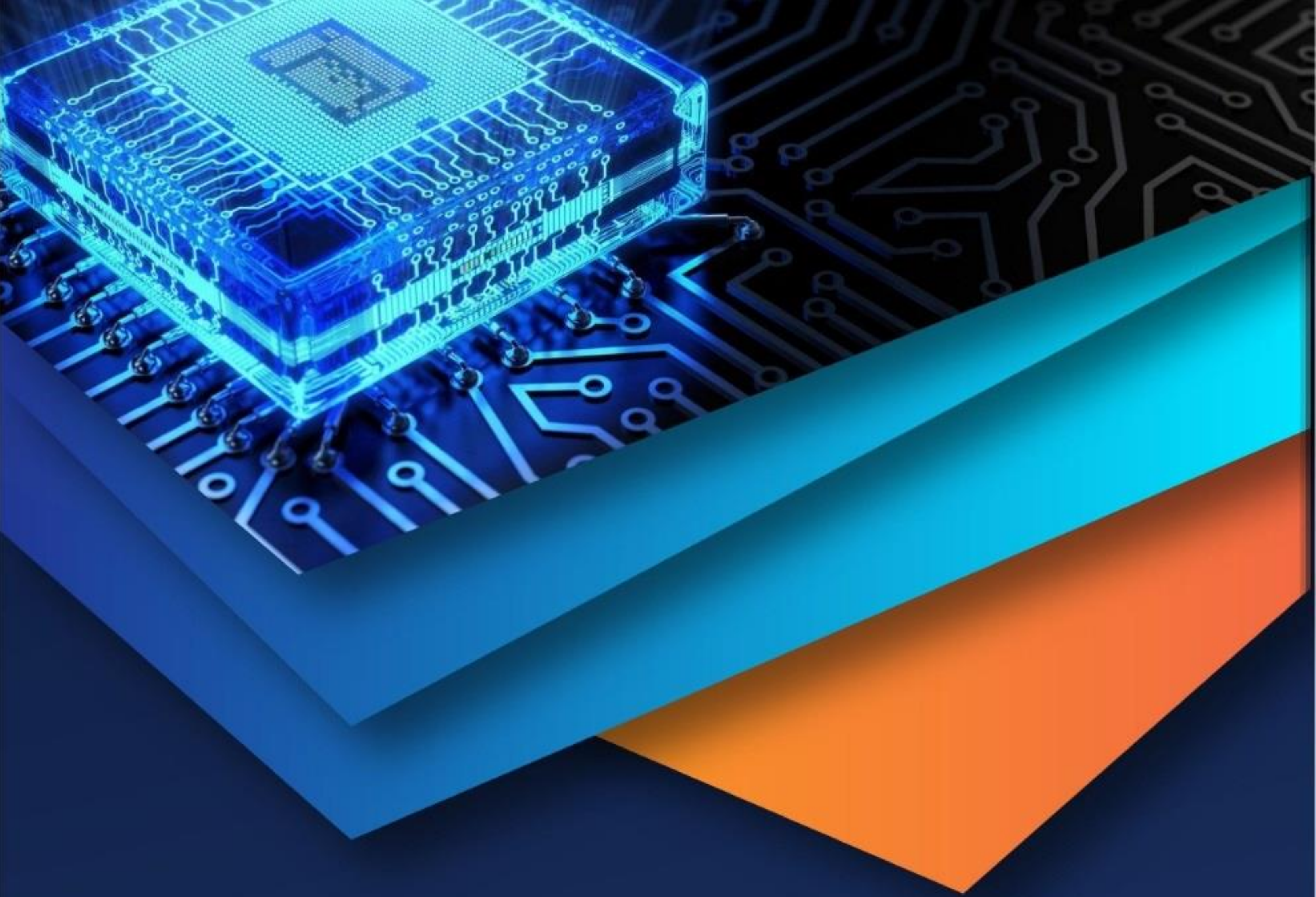

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