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IoT Application in Agriculture: A Spotlight on Indoor Plant Monitoring System-IPMS

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ABSTRACT – The incorporation of Internet of Things-IoT technology in agriculture has ushered in a transformative era, shifting from qualitative, experience-based practices to quantitative, data-driven methodologies in recent years. This paper delves into the world of IoT in agriculture, with a particular emphasis on Indoor Plant Monitoring Systems. This study investigated the practical implications of an IoT framework designed for indoor plant monitoring, to bridge the gap by focusing on improving data collection and visualization capabilities. A prototype-based approach was used, which included DHT11 sensors for temperature and humidity monitoring, a soil moisture sensor, and a watering actuation subsystem. Succulent plants were chosen as resilient samples to test the IoT system's ability to capture and respond to critical parameters because of their capacity to endure changes in environmental conditions and flourish in arid environments. The DHT11 sensor results demonstrated the interconnected dynamics of temperature and humidity, providing the important insights into climate control strategies for optimal plant growth. The data from the soil moisture sensors, combined with manual interventions, demonstrated the IPMS's adaptability in maintaining favorable soil conditions. A point-biserial correlation analysis, in particular, revealed a strong negative correlation (−0.89) between moisture levels and water pump status, confirming the system's efficacy in automated watering. The IPMS demonstrated its effectiveness in leveraging real-time data for informed decison-making, paving the way for future enhancements and comprehensive plant health assessments.

KEYWORDS– ***IoT, Indoor Plant Monitoring System, DHT11 Sensors, Soil Moisture Sensor***

1. INTRODUCTION

The Internet of Things refers to physical objects embedded with sensors and technologies that connect to and exchange data with other devices and systems via the Internet or another type of network, transforming the physical world into a complex and dynamic network of connected devices on an unprecedented scale (*Stanford Online*, 2023) (*OERC*, 2023). IoT has a wide range of applications, from remote patient monitoring in healthcare to automated control in smart homes to optimizing manufacturing processes in Industrial IoT (IIoT) (Sharma, 2020). Smart cities use IoT to manage traffic, waste, and energy more efficiently. IoT is also revolutionizing agriculture by optimizing precision farming for increased yields and resource efficiency. IoT applications benefit automated irrigation, livestock monitoring, and supply chain tracking. Drones equipped with IoT sensors help with targeted crop interventions, and smart greenhouses improve resource efficiency. Weather stations powered by IoT aid in planning for extreme weather, and remote crop management applications provide farmers with efficient monitoring and decision-making tools. Most notably, agriculture monitoring has changed from being a qualitative, experience-based task to one that is quantitative and data-driven due to the introduction of IoT into crop and soil sensing (Chamara et al., 2022). The integration of the IoT in agriculture is one remarkable technological advancement, revolutionizing traditional farming practices and increasing productivity.

The IPMS is the focus of this research on a specific aspect of IoT integration in agriculture. This work is motivated by the convergence of IoT technology and agriculture, with the specific goal of understanding and testing the practical implications of an IoT framework designed for indoor plant monitoring. Succulent plants (Succulents, 2023) were carefully selected as the main subject of this study because of their adaptability, durability, and popularity as indoor plants. Due to their special ability to store water, succulents are suitable examples of plants to study the potential effects of an IoT application in agriculture, particularly indoor plant monitoring. The collection of data over one and a half months allows for a thorough examination of the IoT system's responsiveness to changing environmental conditions for succulent plants.

By providing empirical evidence derived from practical implementation, this study aims to contribute to the growing body of knowledge on IoT applications in agriculture.

2. LITERATURE REVIEW

A comprehensive review of existing literature provides valuable insights into the evolution of automated irrigation systems and their impact on sustainable farming practices when investigating IoT applications in agriculture. Antony et al. (2020) study emphasizes the potential of the Internet of Things (IoT)-enabled precision smallholder farming, demonstrating its ability to improve livelihoods and accelerate the path to self-sufficiency in low- and middle-income countries.

Kim et al., (2020) explored communication technologies such as Wi-Fi, long-range wide area network (LoRaWAN), mobile communication (e.g., 2G, 3G, and 4G), ZigBee, and Bluetooth used in IoT-based agriculture in Korea whereas in Malaysia Ariffin et al. (2020) discovered that an IOT-based automatic monitoring system reduces resources and human efforts while growing oyster mushrooms at optimal temperatures ranging from 20 to 30°C and humidity levels ranging from 70 to 80 percent. Two sensors were placed in the mushroom house's center and corner to measure temperature and humidity, which were then transmitted to the remote monitoring station via a microcontroller unit for further action (Ariffin et al., 2020).

A comparison of an IoT-based controlled environment vertical farming setup versus an uncontrolled setup for Romaine lettuce yielded significant insights into key plant growth parameters. The results show significant differences in the fresh weight of the aerial part, with the automated setup having a higher value of 58.66 g compared to 48.81 g in the unautomated counterpart. This disparity highlights the potential impact of IoT-based control systems on improving plant growth metrics, emphasizing the efficiency and benefits of incorporating technology-driven solutions into vertical farming practices (Kaur et al., 2023).

Regarding the IoT platforms, Rane et al., (2022) developed a system where data generated by IoT devices is sent to the Google Firebase Real-time database hosted on the IoT cloud in this configuration. The information is then transferred to an Amazon Web Services (AWS) server. The AWS server is set up to visualize the data using various gauges, providing real-time insights into the system's current state. Similarly, various types of sensors, such as soil moisture, air pressure, rain detection, and humidity sensors, are used in the work of Saini & Saini, (2020).

Guerrero-Ulloa et al., (2023) proposed the P4L system, which uses IoT technologies to automate the care of ornamental plants to improve indoor air quality. The IoT-based system was created using low-cost Arduino-compatible components and adheres to the Test-Driven Development Methodology for IoT-based Systems. The main objective was in line with the Sustainable Development Goals of the UN, especially the part about enhancing indoor air quality to promote health and well-being (Guerrero-Ulloa et al., 2023).

Marcu et al. (2019) investigated the variation of grapevine leaf wetness, soil and air humidity, and air and soil temperature. Similarly, (Raviteja & Supriya, 2020) intended to provide farmers with an IoT-based Web application for monitoring agriculture fields and conditions, using a low-cost NodeMCU board serving as the primary computing unit.

In the context of India, Sambath et al. (2019) applied IoT in garden monitoring whereas (V, 2021) proposed a model for the smart agriculture monitoring system.

In the context of Nepal, Jha et al. (2020) have contributed to this field by creating a prototype soil moisture-based automated irrigation system developed as per the National Maize Research Program. Similarly, Abhy et al. (2018) investigated the integration of IoT technology with traditional aquaponics, resulting in a hydroponic-aquaculture symbiotic relationship. The indoor setup recirculates water and nutrients to support the growth of terrestrial plants and aquatic life. The monitoring task was accomplished through sensors to monitor pH, temperature (*T*), humidity (*H*), and water levels (moisture (*M*)), with Raspberry Pi as a major computing unit (Dutta et al., 2018).

The reviewed studies demonstrate how versatile IoT technologies are, covering everything from aquaponics and ornamental plant care to automated irrigation systems and precision farming. These examples show the many uses of IoT in agriculture, but they also draw attention to some of the possible difficulties and factors that need to be taken into account. There is a lack of emphasis on robust data collection and visualization. This paper, on the other hand, attempts to fill this void by concentrating specifically on improving data collection and visualization capabilities in the context of indoor plant monitoring.

3. METHODOLOGY

The study on IPMS was initiated by designing and developing a comprehensive framework. This required meticulous planning and the integration of IoT technologies, progressing from concept to functional prototype. The methodology used in this study includes the careful selection and integration of sensors, the establishment of seamless data transmission through the gateway, and the use of cloud-based analytics (ThingSpeak, 2023). Throughout this process, an attempt was made to address three critical parameters for indoor plant health: temperature, humidity, and moisture. Furthermore, extensive primary data was collected from the implemented prototype to validate the efficacy of the IPMS. During this phase, key plant parameters in real time, were monitored and analyzed ensuring the dependability and accuracy of the IoT-enabled system in improving agricultural practices.

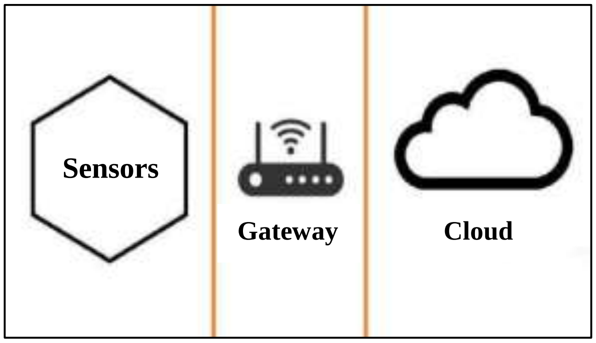

Figure 1. Simplified Architecture of IoT

The three primary parts of the condensed IoT architecture are the sensors, gateway, and cloud as shown in Figure 1. Real-world data is gathered by sensors, processed and aggregated by the gateway, and then stored, analyzed, and interpreted centrally in the cloud. In IoT systems, this simplified structure facilitates effective data management and communication among various applications.

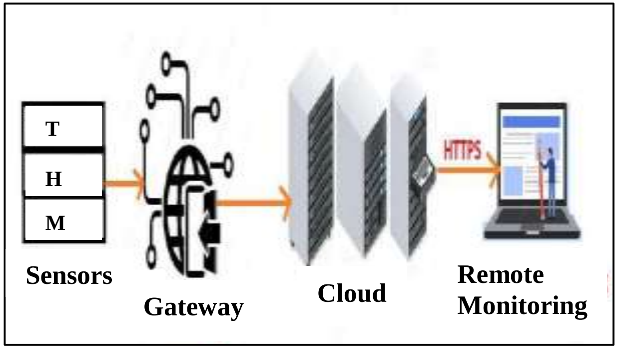

Figure 2. IOT framework of the system

Initially, the data from the mentioned sensors as per Figure 2 is gathered and forwarded to the NodeMCU. After that, NodeMCU uses the internet gateway to send data to a cloud server. The data will now be stored on the server for analysis and presentation.

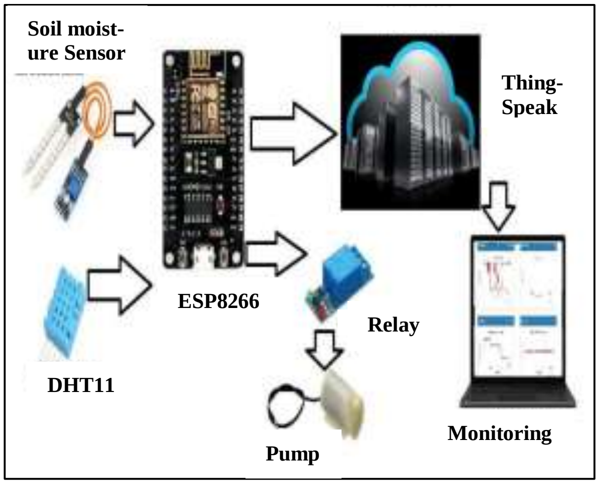

Figure 3. Major modules of the IoT-based IPMS

The soil moisture sensor as shown in Figure 3 is a versatile and cost-effective solution for monitoring soil conditions in agricultural and environmental settings. With a power range of 3.3 to 5V, it offers compatibility with various systems. Its compact dimensions, measuring approximately 3cm x 1.5cm for the module and 6cm x 3cm for the soil probe, make it easy to integrate into different environments. The dual output modes, supporting both analog and digital outputs, provide users with flexibility based on their specific needs. One of the notable features is its affordability, making it accessible to a diverse range of users, from small-scale gardeners to large-scale agricultural operations.

The DHT11 temperature and humidity sensor boasts specifications that make it a reliable and affordable choice for various applications. Operating on a power range of 3 to 5V, it is compatible with a wide array of electronic systems. The sensor provides accurate temperature readings within a range of -20°C to 60°C with a precision of ±2°C. Simultaneously, it offers humidity measurements in the range of 5% to 95% with a ±5% accuracy. The compact dimensions of 12mm x 12.2mm x 5.5mm make it suitable for space-constrained installations. With four pins for easy connectivity, the DHT11 sensor is user-friendly, allowing seamless integration into projects.

The ESP8266 microcontroller is used by NodeMCU, an open-source IoT platform, to provide a versatile solution for IoT projects. It operates at an 80 MHz clock speed and provides dependable wireless connectivity via built-in Wi-Fi (802.11 b/g/n), allowing devices to connect to the internet seamlessly. NodeMCU provides flexibility and ample storage capacity with a standard operating voltage of 3.3V, a variety of GPIO pins, and 4MB of Flash memory. Its USB connectivity makes programming and debugging easier, and its Lua scripting support allows for faster development. The NodeMCU's compact form factor, which is typically presented as a development board, ensures ease of integration into a variety of projects. Furthermore, the active and supportive community surrounding NodeMCU adds to its popularity, making it a preferred choice for developers looking for a robust and accessible platform for IoT applications.

ThingSpeak is an IoT platform for collecting, analyzing, and visualizing sensor data. ThingSpeak provides data channels for organized storage, APIs for programmable interfacing, and integration with MATLAB for advanced analytics. Notably, it supports the MQTT (Message Queuing Telemetry Transport) protocol (Egli, 2017), a lightweight messaging system popular in IoT applications. It operates on a publish-subscribe model, allowing devices to publish messages to specific topics and others to subscribe for real-time communication. ThingSpeak provides a comprehensive solution for IoT projects, with features such as ThingSpeak React for defining data-driven reactions, Time Control for scheduling actions, and built-in visualization tools for creating charts and maps. Its adaptability and compatibility make it a user-friendly platform for efficiently connecting and managing various IoT devices.

Figure 4. Experimental setup at Digital Laboratory, Kathford, Lalitpur

The experimental setup for IPMS was established at Kathford International College (Engineering Block)'s Digital Laboratory as shown in Figure 4. Soil moisture sensors and DTH11 sensors are utilized in this system to sense temperature and humidity. The sensors continuously gather data and transmit it to the NodeMCU. The ESP8266 wi-fi module on the board then be used to transmit the data to the thinkspeak cloud platform for additional processing and data visualization. Subsequently, the user receives continuous updates on the field's condition via the web-based platform. The system for the watering actuation subsystem was designed for watering the plant as well where the soil moisture sensor is checked by the system to see if it is below the threshold value i.e. 15%. The watering actuation system initiates automatically when the measured moisture data falls below the threshold value and will cease when the desired level of moisture is detected. An electromechanical switch-relay module is utilized which powers up the water pump for watering accordingly.

The data was collected from February 15, 2023, to April 1, 2023. The collected data was obtained in CSV format through the ThingSpeak cloud platform. Following that, the data was analyzed using Google Colab, leveraging Python programming. To program the NodeMCU, the Arduino IDE (Arduino, 2024) was used. This integration enabled the utilization of the familiar and user-friendly environment of the Arduino IDEs for coding and uploading firmware to the NodeMCU.

4. RESULTS AND DISCUSSION

Throughout the observation period, plenty of data was gathered, providing insights into how well the IPMS responded to shifting environmental conditions. This section provides a thorough analysis of the DHT11 sensors' data, providing insight into the fluctuations in humidity and temperature in the monitored area. The results of moisture sensors, which are essential for measuring the moisture content of the soil that is necessary for plant growth are also discussed.

The goal is to present raw data as well as meaningful patterns, trends, and correlations that contribute to a better understanding of the indoor plant ecosystem. By doing so, the way is being paved for informed decision-making in climate control, watering strategies, and overall management practices.

4.1 Results obtained from DHT11 sensor

Temperature readings as shown in Figure 6 increased over the observation period, indicating changing climatic conditions within the monitored room. This upward temperature trend was accompanied by corresponding fluctuations in humidity as shown in Figure 5, demonstrating the interconnected nature of these environmental variables. The successful acquisition of this extensive dataset provides an accurate representation of the ambient conditions in the room throughout the study period. The precise measurements taken by the DHT11 sensors provide a solid foundation for understanding the environmental nuances that affect the health of indoor plants.

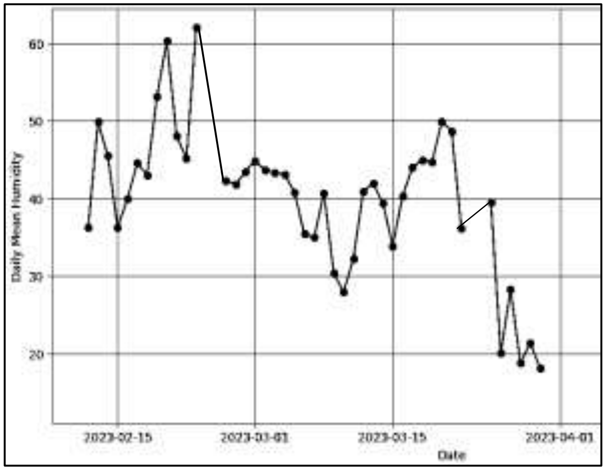

Figure 5. Line plot for daily mean humidity over time

The interaction of temperature and humidity is critical for the health and growth of indoor plants. The rising temperature, as detected by the DHT11 sensors, has the potential to affect plant transpiration rates, nutrient absorption, and overall metabolic processes. Concurrently, humidity levels have a significant impact on the plant's ability to regulate water loss and maintain optimal turgor pressure.

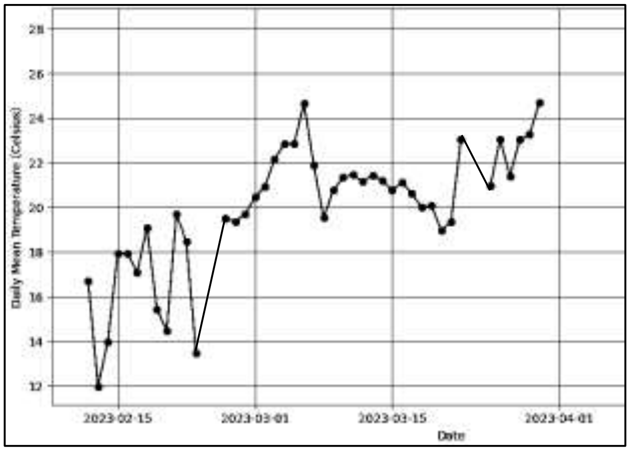

Figure 6. Line plot for daily mean temperature over time

These new insights into temperature and humidity dynamics allow for more informed indoor plant management. Plant caretakers can implement precise climate control strategies by understanding how these variables fluctuate, ensuring that the indoor environment remains conducive to the specific needs of the monitored plant species. As a result, the accurate data obtained from the DHT11 sensors serves as the foundation for effective decision-making in fostering a healthy and thriving indoor environment.

4.2 Results obtained from soil moisture sensor

The data from soil moisture sensor provides important insights into the dynamic patterns of moisture levels within the monitored soil environment. The recorded observations provide a thorough understanding of how soil moisture fluctuated throughout the study, highlighting key moments and interventions.

As shown in Figure 7, the monitoring began with a soil moisture level of 70%, indicating that the soil had a relatively high moisture content. This could be due to previous watering or environmental factors. After 9-10 days, soil moisture gradually decreased to around 35%, indicating a natural decrease over time. Manual watering interventions were implemented to address this decline, indicating a hands-on approach to maintaining optimal soil moisture levels.

The researcher took a proactive measure as the soil moisture levels approached the predefined threshold value of 15%. The researcher accessed the pump status using the real-time data available on ThingSpeak and, upon detecting the pump on status, initiated a manual intervention by pouring water. This dynamic response mechanism exemplifies the incorporation of IoT technology into decision-making, allowing for timely and precise actions based on continuously monitored soil moisture conditions.

A significant increase in soil moisture levels to 120% was observed around 2023/03/15, which is attributed to manual pouring. This elevation above the typical range demonstrates the system's ability to adapt to changing conditions, even if it exceeds the predefined threshold. The soil moisture sensor's consistent and responsive nature, combined with the implemented watering mechanisms, confirms the reliability of the obtained data. Visual observations were conducted in conjunction with the soil moisture sensor data to assess the overall health of the plant within the experimental setup. Despite the manual decision-making process for watering the plant kept in the vessel, visual inspection revealed that the plant was in good health. The method of visual observation provided a qualitative understanding of the plant's condition, revealing no visible signs of stress, wilting, or other issues. The positive visual observation corresponds to the soil moisture sensor data

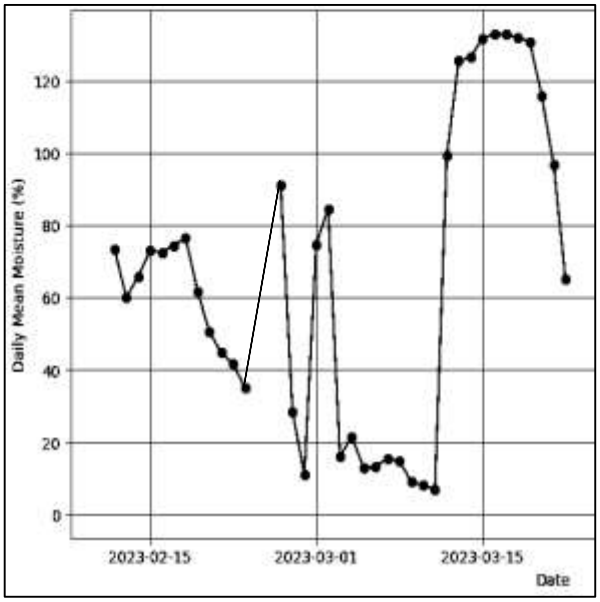

Figure 7. Line plot for daily mean moisture over time

implying that the manual watering decisions implemented were effective in maintaining a favorable soil moisture environment for the plant.

Further, a point-biserial correlation analysis was performed on the data obtained in CSV format to investigate the relationship between, moisture levels and water pump status in the monitored system. The analysis found a strong negative correlation of -0.89, indicating a strong and statistically significant relationship between these two variables. It means, that as the moisture levels rise, the water pump status tends to be off, and as the moisture levels fall, the pump status tends to be on. This correlation is consistent with the expected behavior of an automated watering system, which adjusts the water pump status based on real-time moisture readings to maintain optimal soil moisture levels for plant health.

When comparing these findings to the existing literature, Antony et al. (2020) emphasized the potential of IoT-enabled precision farming, which aligns with the intention to leverage IoT for informed agricultural decision-making. Kim et al. (2020) investigated communication technologies in IoT-based agriculture, which parallels the use of IoT devices and cloud platforms for data visualization. The comparison to Kaur et al. (2023) demonstrates the effectiveness of IoT-based control systems in improving plant growth metrics.

Similarly, Rane et al. (2022) and Saini & Saini (2020) use of IoT platforms resonates with an approach of utilizing ThingSpeak for real-time data visualization. Guerrero-Ulloa et al.'s proposed P4L system is consistent with the emphasis on IoT for automated plant care. The work of Jha et al. (2020), Abhy et al. (2018), Sambath et al. (2019) in Nepal, and Sambath et al. (2019) in India correlates to this investigation of IoT in agricultural monitoring systems.

Finally, these findings add to the growing body of knowledge on IoT applications in agriculture, validating IPMS's potential for data-driven plant management. The findings are consistent with and extend previous research, emphasizing the transformative impact of IoT in improving agricultural practices and sustainability.

5. CONCLUSION

IoT-based Indoor Plant Monitoring System successfully captured and analyzed critical temperature, humidity, and soil moisture data, providing valuable insights into the dynamic interplay between environmental conditions and plant health. The DHT11 sensors enabled informed climate control strategies for optimal plant growth by providing a nuanced understanding of temperature and humidity fluctuations. The soil moisture sensor data, combined with manual interventions, demonstrated the system's adaptability in maintaining favorable soil conditions.

To sum up, this experimental study fills an essential gap by emphasizing the importance of reliable data collection and visualization in the context of indoor plant monitoring. The IPMS demonstrated its effectiveness in leveraging real-time data for decision-making, which corresponded with studies focusing on IoT-enabled precision farming and automated plant care systems.

6. LIMITATION AND RECOMMENDATION

It's worth noting that, while a framework with a watering actuation system was designed, the emphasis was on automatic control. During the initial phase of testing, the actual watering process was carried out manually in the laboratory to ensure the well-being of the plants.

While visual assessments are useful for gaining preliminary insights, future research could benefit from including additional metrics or technologies to provide a more comprehensive assessment of plant health. Leaf color analysis, biomass measurements, and other non-invasive sensing techniques to quantify physiological parameters are examples. The IPMS can be improved in the future by incorporating additional sensors for a more comprehensive data set, experimenting with advanced analytics techniques, and developing a dedicated mobile application for real-time access.

7. ACKNOWLEDGMENTS

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