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A smart oyster mushroom cultivation using automatic fuzzy logic controller

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Abstract

Oyster mushroom cultivation is an eco-friendly, profitable agribusiness because of its nutritious and medicinal value but it is labor-intensive, and it grows in a sensitive environment. It must use an autonomous environment control system to optimize and offer the necessary growing conditions. To optimize the temperature and humidity and consequently maximize mushroom production, a smart mushroom watering, monitoring, and controlling system using fuzzy logic controllers (FLC) have been developed. This study suggests installing an Internet of Things (IoT) node that uses DHT22 sensors, an ESP32 board, and relays to control actuators (sprinkler, cooling fan, humidifier, and heater) in a smart oyster mushroom house. The controller on sensing current temperature and humidity values using the fuzzy logic technique switches on/off the actuators automatically. The data collected at each IoT node is collected and visualized on the ThingSpeak platform. The computed response time for actuators using FLC is compared with that calculated using a simple ON-OFF method. The findings demonstrate that response time calculation using fuzzy logic is significantly accurate and faster than a simple ON-OFF approach. Additionally,

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the graphs created in live on ThingSpeak, demonstrate that the FLC algorithm is more robust and effective than the simple ON-OFF algorithm.

Subject Classification: *03BXX, 03B52.*

Keywords: *Precision agriculture, Smart mushroom cultivation, Internet of Things, Fuzzy logic controller.*

1. Introduction

Food security is a multifaceted idea that reduces malnutrition by assuring a steady supply of wholesome food. It is becoming a significant global concern because of a number of anthropogenic factors, including fast population increase, urbanization, industrialization, the loss of farmland, a lack of fresh water, and environmental degradation [1]. The population of world is estimated to grow by 1.1% annually to approximately 9.7 billion from the current population of 7.7 billion by 2050 [2]. Agriculture is the key industry that will feed this big population and support worldwide sustainable economic growth. However, as the population of world increases, so do agricultural food demands, necessitating a change from conventional farming practices to smart agricultural practices, also known as agriculture 4.0. However, to add standard to an agricultural product is a challenge to achieve.

In the current era, IoT is playing a vital role to produce agricultural data for productivity improvement from agricultural industries 4.0. The IoT application and research present various techniques to support agronomist in overcoming obstacles, including water shortages, a lack of adequate land for agricultural plantations, difficulty with cost management, and achieving the rising worldwide demand for food resources. Oyster mushroom cultivation offers many opportunities to overcome the problem faced by agricultural industries, because of its high nutritional value, and medicinal use, and can be cultivated in small rooms as well. Hence, its demand is increasing globally. In 2013-14, the production of mushrooms in India was only 17.1 metric tons, whereas in 2020-21 it increased to 243 metric tons (www.indiastat.com). The key problems with mushroom cultivation are with irrigation, monitoring environmental parameters, and minimizing human intervention. IoT technologies take the credit for developing and designing smart mushroom cultivation process and distributing it through various social channels to farmers, intend to help them to raise the quality, quantity, sustainability and a cost effective mushrooms.

Oyster mushroom requires proper platform for its growth particularly comprise of significant temperature and humidity, responsible to retain quality and quantity. It may grow vigorously in environments with humidity levels ranging from 70% to 85% and temperatures between 22 °C and 27 °C [3]. As the mentioned criteria requires a significant investment to build air-conditioned farms, farmers prefer a simple and low-cost wood building area without proper climate controller or an open-air hut type structures using gunny sheets. Mushrooms cultivation without implementing proper environmental conditions affected by different unknown climatic parameters, which can be seasonal, that can change the humidity and temperature of designated area (mushroom house) which can leads to bad quality mushrooms [4]. To overcome this problem, oyster mushroom cultivation needs an automatic environment system, which helps farmers in irrigation, and monitoring the temperature and humidity of mushroom houses with no human intervention. It needs a complex, nonlinear, time series, and strongly coupled environmental control system, which will keep optimum temperature and humidity in the oyster mushroom house. The study has been done on various systems and mechanisms, which are used to control greenhouses; Xue-Bo Jin et al. have proposed an IoT-based environment-sensing system for greenhouse using a bidirectional self-attentive encoder-decoder framework (BEDA) that predicts temperature, humidity, and CO_2 level from IoT-based sensors [5]. P. Javadi Kia et al. have simulated an automatic environmental closed-loop control system for a greenhouse using the FLC in MATLAB with soil moisture and calculated the period for irrigation to open/close the hysteric valve [6]. R. Santhana Krishnan et al. have developed an intelligent irrigation system to control water pumps operated with ON/OFF logic using FLC [7]. Songwei Zeng et al. have simulated a hybrid control strategy, combining Radial Basis Function (RBF) network with conventional proportional, integral, and derivative (PID) controllers for greenhouse climate control [8]. Romeo Urbieta Parrazales et al. have implemented an automatic irrigation control system using an FLC for rose cultivation by considering controllable variables such as temperature and humidity, and implementation is done using a field-programmable gate array (FPGA) in a domestic greenhouse [9]. Choudhary et al. implemented a novel observer design used to control different parameters of greenhouse to optimize poser consumption and water use using PID and Fuzzy controller [10]. In recent years, there are very few automatic controllers are developed to control various types of mushroom houses using various computing techniques. As per [11] an exclusive supervisor and water control mechanism using new wireless programmable logic controller (PLC) was implemented for oyster mushrooms cultivation. Murali Padmanabha et al. have designed and implemented an h/w and s/w-based framework for a mushroom automatic environmental control system [12]. S. Vellingiri et al. have used machine learning with a predictive analysis approach for predicting the disease in mushrooms from history using Internet of Things devices and Kalman filter and then classifying using a decision tree algorithm [13]. Saiful Azimi has developed an automatic environmental control system based on simple ON/OFF logic to control parameters temperature, humidity, and CO_2 of mushroom house and implemented it using Node MCU ESP8266 V2.0 [14]. Ibrahim Mat et al. have used a feedback control system to optimize temperature, humidity, and CO_2 values for Shiitake mushroom cultivation [15]. G P Cikarge et al. have implemented an automatic humidity controller using FLC to optimize the humidity of oyster mushroom houses [3]. Although there are already mushroom house controller designed and implemented, the results and analysis performed further demonstrate that the temperature and humidity are not achieved within an exact range but rather close by. In addition, the controllers used are either PLC or an Arduino controller for data acquisition and control, which are expensive.

This paper encompasses to develop a cost effective an automatic fuzzy logic controller designed for watering, monitoring, and controlling the humidity and temperature of the oyster mushroom house, based on fuzzy inferences to provide optimum response time (switching ON-OFF time) for the water pump (sprinkler), humidifier, fan, and heater. Fuzzy logic is a soft computing technique used in classic control to solve non-linearity problems [16] and decision support systems [17]. In addition, it assists the execution of any system into logical processes, like a human brain, which could improve new technologies according to system requirements. It is used to maintain the ideal temperature and humidity levels for oyster mushroom production. As per designed system, two DHT22 sensors are deployed to sense temperature and humidity inside and outside the mushroom house. An affordable ESP32 board is depicted for data collecting and the control function, as it has a built-in Wi-Fi module that keeps the required environment. The temperature and humidity of the mushroom house are controlled using a fuzzy-based open-loop controller, which provides decisions for actuating sprinkler, humidifier, fan, and heater. This helps the system to retain the mushroom house temperature in the range of 22 °C and 27 °C and humidity between 70% to 85%. The data sensed and generated by the controller is collected and visualized in the ThingsSpeak. To help farmers in analyzing the expenses, all of these databases can be utilized to forecast future production and strategy mushroom farming. Additionally, the effectiveness of FLC is compared to that of a simple On-Off controller approach for the heater, fan, humidifier, and sprinkler response times. With the help of the research's findings, farmers will be able to raise production and quality of yield to increase their revenues with efficient and low cost controller.

2. Proposed Methodology

2.1 *Smart Oyster Mushroom House with wireless IoT node*

Oyster mushrooms can be cultivated on small scale as well as on large scale. This work focuses on small-scale mushroom production with real-time situations on positioning two mushroom farms apart from each other. These farms included embedded IoT nodes to regulate temperature and humidity. A simple On-Off approach is incorporated into the controller of the IoT node in the farm 1, whereas the FLC algorithm is incorporated into the controller of the IoT node in farm 2. Each IoT node consisting of two DHT22 sensors (one for sensing temperature and humidity inside the house and the other used for sensing temperature and humidity outside the house), an ESP32 controller with a built-in Wi-Fi module, and relays for actuators (sprinkler, humidifier, fan, and heater) as shown in Fig. 1 (a) and (b). The other sensor is intended to keep track of the outside temperature and humidity of the farm and to compare those readings during data

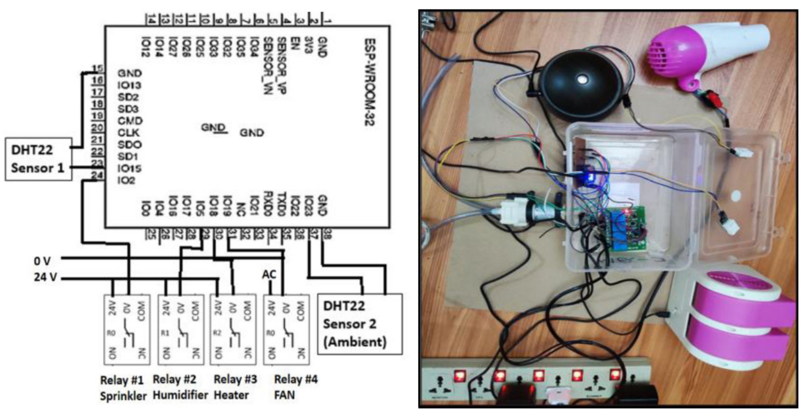


Figure 1

(a) Schematic diagram of wireless IoT node (b) Wireless IoT node for installation

processing. The IoT node sends data about temperature, humidity, ambient temperature, and ambient humidity, response time for the water sprinkler, humidifier, cooling fans, and heater to the ThingSpeak platform continuously after every thirty seconds. Each IoT node is responsible for watering, monitoring and controlling the actuators, including device management and data collection for mushroom farms. The data collected by sensors is broadcasted on the ThingSpeak platform through the ESP32 Wi-Fi module. Based on FLC or On-Off approach the ESP32 control component processes the data to regulate actuators inside the farm. The board is connected to a computer through the RS232 connector so that the operators can program it.

2.3 *Design and implementation of Fuzzy Logic Controller*

A fuzzy logic controller is a soft computing technique used to monitor nonlinear systems. It assists the execution of any system into logical processes, like a human brain, which could improve new technologies according to system requirements. Hence, it is a suitable technique to develop an automatic environmental control system [9]. FLC can be implemented in two ways; the Mamdani approach gives output in the form of crisp value only, and the Takagi-Sugeno-Kang approach gives output in mathematical analysis. In both methods, there are three steps to be followed fuzzification, an inference engine (rule base), and defuzzification. As mushroom cultivation requires a system, which is working in uncertain conditions, the Mamdani approach is being selected. This approach gives output in terms of fuzzy values in place of a mathematical equation and gives an effective performance in uncertain conditions. The values of temperature and humidity obtained from sensor 1 are the inputs to FLC, while the times for sprinklers, humidifiers, cooling fans, and heaters are the outputs. In fuzzification, the membership function (MF) for temperature and humidity is selected as trapezoidal with membership values Cold, Suitable, Hot and Dry, Suitable, Wet respectively as shown in Fig. 2. The trapezoidal MF has membership values, which slowly increase to particular values, and then remain steady for a period and again start decreasing slowly. Hence, it will help to keep the mushroom house temperature in the range of 22°C to 27°C and humidity in the range of 70% to 85%. The output of FLC is designed with response time for all actuators in seconds using triangular MF as shown in Fig 2. Next, using expert knowledge, and trial and error method, a set of IF-THEN rules known as a fuzzy rule base, is created to take into account

Table 1
Fuzzy rule base

Rules	Input Variables					Output Variables			
	Temperature		Humidity			Sprinkler Time	Humidifier Time	Fan Time	Heater Time
1	Cold	AND	Dry	THEN		Short	Short	Off	Short
2	Suitable	AND	Dry	THEN		Medium	Medium	Off	Off
3	Hot	AND	Dry	THEN		Long	Long	Long	Off
4	Cold	AND	Suitable	THEN		Off	Off	Off	Medium
5	Suitable	AND	Suitable	THEN		Off	Off	Off	Off
6	Hot	AND	Suitable	THEN		Medium	Off	Medium	Off
7	Cold	AND	Wet	THEN		Off	Off	Off	Long
8	Suitable	AND	Wet	THEN		Off	Off	Off	Medium
9	Hot	AND	Wet	THEN		Short	Off	Short	Short

the output of the FLC. The rules are described in Table 1. Defuzzification is done using the most common center of gravity (COG) method [9]. It entails determining the centroid of the region enclosed by the controller output MF, and using its abscissa as the precise controlling value [18][19]. The defuzzification process produces a precise output in the form of time, which can be used to calculate how long the heater, humidifier, cooling fan, and sprinkler will be ON. The results are plotted in surface plots, and are shown in Figure 3.

The design of FLC is carried out in MATLAB Simulink as per the above specifications. The .fis file is then converted into the .ino file to upload it to the ESP32 controller. The controller determines the response time by setting a real-time clock (RTC) and data is sent to ThingSpeak cloud after every thirty seconds. The times for the sprinklers, humidifier, cooling fan, and heater are calculated in FLC code and sent to ThingSpeak through Wi-Fi. The Wi-Fi module starts the communication setup and uses serial I2C communication mode. The mushroom farm is capable to meet the ideal humidity and temperature for oyster mushrooms both during the day and at night.

2.4 *Design and implementation of On-Off Controller*

The On-Off controller has a simple logic to monitor and control mushroom farm 1. The IoT node deployed in mushroom farm 1 has a

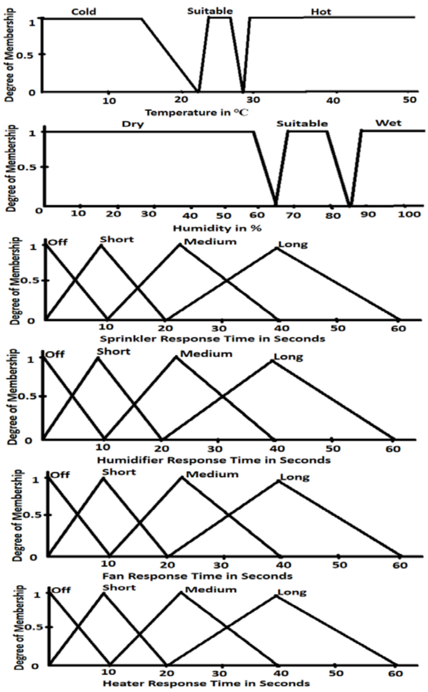


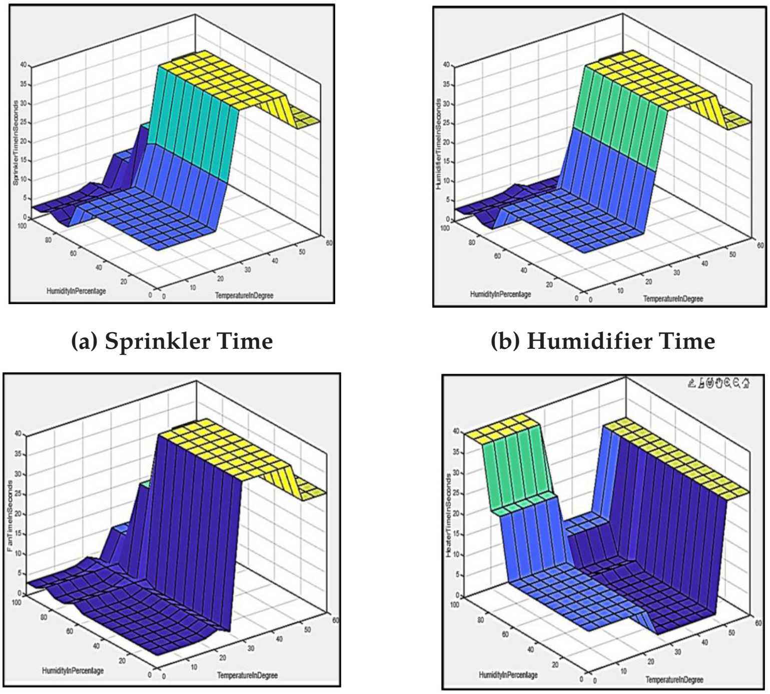
Figure 2

Design of membership functions for input and output in FLC.

similar design and specification as that of designed and built for farm 2. The only difference is software implementation and logic. The algorithm integrated in simple On-Off controller is as shown in flowchart in Fig. 4. A simple On-Off controller and FLC have significant differences in, the output devices in FLC are activated depending on the fuzzy value's degree of membership. However, a simple On-Off controller maintains exact threshold value to activate output devices. As a result, the actuator is turned on even when it is not necessary to keep the temperature or humidity constant.

3. Experimental Results

An experiment was done with mushroom farming to assess how well the smart oyster mushroom farm worked using IoT node. Oyster mushroom spawn was used at each of the two developed open-air mushroom farms as shown in Fig. 5. At each farm, the temperature and humidity levels



(a) Sprinkler Time **(b) Humidifier Time**

(c) Fan Time **(d) Heater Time**

Figure 3

Output surface plots for actuators response time.

were detected and recorded in real time on ThingSpeak. The room's center was equipped with temperature and humidity sensors. The sprinkler is a water tube with small holes and connected with water pump, installed on sidewalls of farms to wet gunny sheets covering the farm. Cooling fan, humidifier and heater are installed at the center of each farm. At each farm, a separate set of ESP32 controllers oversaw the operation of this equipment. All the data collected during FLC controlling is collected on ThingSpeak including ambient temperature and humidity as shown in Fig. 6. While a simple On-Off algorithm is uploaded for controlling in farm 1, the FLC algorithm is integrated into the controller in farm 2. After controlling the response time of actuators (sprinkler, fan, humidifier, and heater) are send on ThingSpeak and visualized graphically on its dashboard as shown in Fig. 7. The farmers may access these statistics through their cell phone at any time and from any location via ThingSpeak web, allowing them

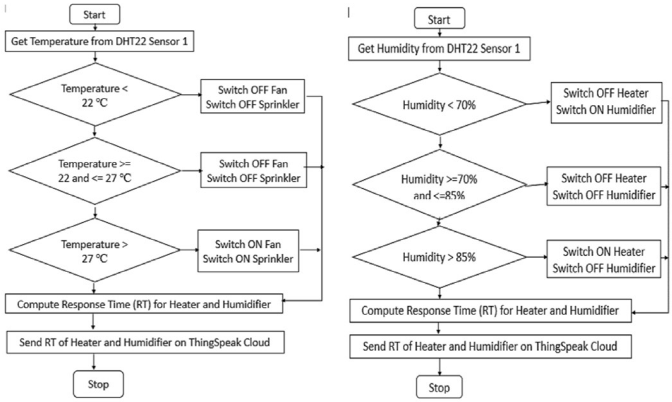


Figure 4

Flowchart of Simple On-Off controller (a) for temperature (b) for humidity.

Figure 5

Mushroom farm structure (a) Outside the farm (b) Inside the farm

to study the conditions inside the mushroom farm and can strategy its farming accordingly. According to the ThingSpeak dashboard, the FLC can keep the temperature between 22°C and 27°C relative to the ambient temperature and the humidity between 70% and 85% relative to the ambient humidity. This results shows that the proposed FLC method was successful in controlling the farm’s conditions to the desired levels.

The comparative results for controlling temperature between the suggested FLC and simple On-Off operating systems are shown in Fig. 8. In the graph, the x-axis represents the temperature value and the y-axis represents response time of sprinkler, humidifier, fan and heater for FLC and simple On-Off controller respectively. According to the graph, the

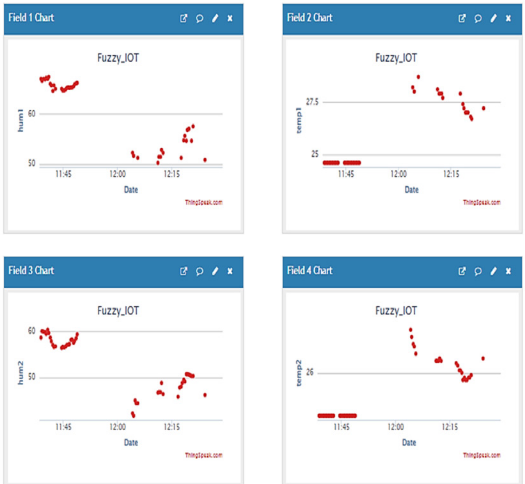


Figure 6

ThingSpeak dashboard showing real time charts for input (a) humidity and ambient humidity (b) temperature and ambient temperature.

FLC controller's response time range is 0 to 45 seconds, but the On-Off controller's range is 0 to 1000 seconds to control temperature. Additionally, Fig. 9 displays the humidity control comparison findings between FLC and On-Off controller. The humidity value is shown on the x-axis of the charts, and the response times for all actuators are shown on the y- axis. It demonstrates that the On-Off controller's response time ranges from 0 to 1400 seconds, whereas the FLC controller's response time is 0 to 40 seconds. This indicates that the FLC controller requires less time than an On-Off controller does, to bring temperature and humidity into the desired range. Finally, the FLC performs better than the On-Off controller in terms of electricity consumption and system durability, as it provides lesser time to perform.

4. Conclusion

A smart watering, monitoring, and controlling system for oyster mushroom farms is proposed and implemented using affordable and effective ESP32 device to increase efficiency for low-cost mushroom farms. The proposed smart system has used FLC diagnostic to adjust the temperature and humidity for mushroom house in desired ranges on actuating sprinkler, humidifier, cooling fan and heater. The detected temperature and humidity are sent wirelessly to the ThingSpeak platform.

Figure 7

ThingSpeak dashboard showing real time charts for output response time for humidifier and fan sprinkler and heater

Planning cultivation and predicting productivity are two uses for all these databases.

The performance of FLC system was tested in an experimental setting, and its responsiveness has been compared to that of a simple On-Off system to evaluate its robustness. As a result, both the systems has been monitored continuously through ThingSpeak dashboard as well as physically. The FLC controller requires less time than an On-Off controller does, to bring temperature and humidity into the desired range. As On-Off controller unnecessarily keeping the actuators on due to its exact set points for temperature and humidity, the FLC has performed better than On-Off controller in terms of calculating response time and cost. In conclusion, the smart mushroom farm provides farmers with a practical, cost effective and efficient approach for growing oyster mushrooms in small scale. In future, the response time for actuators can be more improved on combining the soft computing fuzzy logic with artificial neural network and performance of system can be studied.

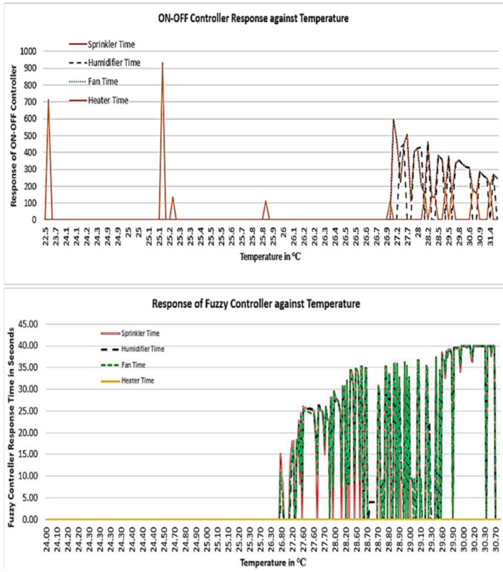


Figure 8

Comparison of response time against temperature between FLC and On-Off controller

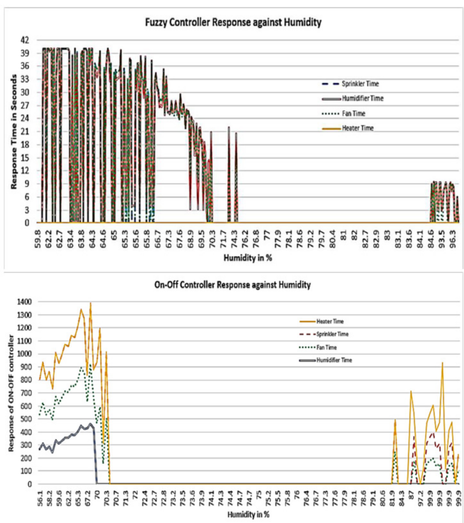


Figure 9

Comparison of response time against humidity between FLC and On-Off controller

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