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Remote-Control System for Greenhouse Based on Open Source Hardware

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Abstract: With the development of technologies such as the Internet of Things and Big Data, agriculture is entering the digital age. Modern information technology and intelligent equipment are the development direction of agriculture. In this paper, a remote-control system for greenhouse environment was developed based on Raspberry Pi, MySQL and Android. The system consists of a greenhouse control system (subsystem A), an environment monitoring system (subsystem B), a MySQL remote database (subsystem C), and an Android monitoring software (subsystem D). The subsystem A is used to implement automatic fertigation and collect data from subsystem B, which will be uploaded to cloud server database (subsystem C). The subsystem B is used to monitor the environmental parameters in the greenhouse such as air temperature/humidity, soil temperature/humidity etc. The subsystem C is used for storage of greenhouse environment data and communication between subsystem B and subsystem D. The subsystem D is used for data visualization including real-time display, storage and analysis of greenhouse environmental data, and remote control of fertigation system including the EC/pH control of the fertigation solution, irrigation scheduling, and fertigation settings. A proportional-integral-derivative (PID) control algorithm is used for the fertigation process of the subsystem A. The low-power LoRa technology is used for subsystem B to achieve low-power long-distance data transmission, which is especially suitable to greenhouses. All monitoring settings can be operated remotely by users.

Keywords: Greenhouse control, Python, Java, PID, LoRa

1. INTRODUCTION

Smart agriculture has become a new trend in agricultural development. Modern information technology based on Internet of Things (IoT), Big Data, Cloud Computing, etc. is widely used in modern agricultural production (Elijah et al., 2018; Wolfert et al., 2017; Wu et al., 2018). The greenhouse is the main place for combining modern information technology with traditional agricultural models. The smart greenhouse will be one of core representatives of smart agriculture (Elijah et al., 2018; Kodali et al., 2016; Li and Lin, 2014).

In the smart greenhouse sector, a lot of researches have been conducted, such as greenhouse fertigation (Wu et al., 2019), automatic shutter rolling (Zhang et al., 2019), environmental monitoring system (Kodali et al., 2016), photothermal control (Pitakphongmetha et al., 2017) and so on. In order to realize a smart greenhouse, it is a major challenge to establish a reliable greenhouse control model and develop a model-based intelligent control system based on greenhouse environmental data (Su et al., 2017; Vanthoor, 2011).

In this paper, a new remote-control system for greenhouse environment was developed based on our previous work (Wu et al., 2019), including a fertigation system and a greenhouse environment monitoring system. The greenhouse environment monitoring system was developed based on LoRa (LoRa, 2019) that could effectively collect greenhouse temperature and humidity in real-time while maintaining low power consumption and energy. Also, necessary software was designed and implemented to achieve remote control of greenhouse fertigation and environment monitoring. The design approach of this system is universal and able to install more sensors to access more environmental parameters in the greenhouse, such as illumination intensity, CO_2 concentration, etc., which will contribute to greenhouse big data analysis and control modelling.

2. MATERIAL AND METHODS

2.1 System structure

The remote-control system developed for greenhouse environment mainly included four subsystems, as shown in Figure 1. Subsystem A is the greenhouse control system, subsystem B is the greenhouse environmental monitoring

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system, subsystem C is the MySQL remote database, and subsystem D is the Android monitoring software. Subsystem A, C and D communicate with each other via TCP/IP. Subsystems A communicate with subsystem B via LoRa protocol.

2.2 Greenhouse control system

Compared to our previous system (Wu et al., 2019), the new developed greenhouse control system used Raspberry Pi 3B+, a low-power open source hardware, as the controller and E32-TTL-100 module based on LoRa protocol to communicate with subsystem B. The Raspberry Pi 3B+ is the latest product in the Raspberry 3 range. It is based on the ARMv8 architecture and supports PoE Ethernet interface and 2.4/5 GHz IEEE 802.11.b/g/n/ac wireless network interface, with 40 general-purpose input and output pins (Raspberry pi, 2019). Furthermore, the Raspberry Pi 3B+ with Raspbian computer operating system supports Python programming, which lets you work more quickly and integrate your systems more effectively (Python, 2019).

The greenhouse control system consists of Raspberry Pi controller and peripheral circuits, 4 stock solution tanks (tank A, tank B, tank C, tank D), acid tank, venturi, solenoid valves, mixing tank, EC/pH sensors, inlet pipe, and outlet pump (Wu et al., 2019). The venturi was used to generate vacuum negative pressure to absorb fertilizers from the solution tanks. The solenoid valves were used to control the absorbing rates. The EC/pH sensors were installed in the mixing tank (two of each). The outlet pump was used to operate the fertigation and meanwhile provide drive power for the venturi.

The EC value, pH value, fertilizer ratios and fertigation schedule (including irrigation start time, irrigation frequency, single irrigation time, etc.) can be set via the Android software, and then synchronized to the MySQL database and the greenhouse control system. Then the system controls the fertilizer absorbing rate through the solenoid valves based on the PID algorithm, so that the EC/pH value of fertigation solution in the mixing tank reach the set value, and finally the fertigation solution is applied to crops via the outlet pump.

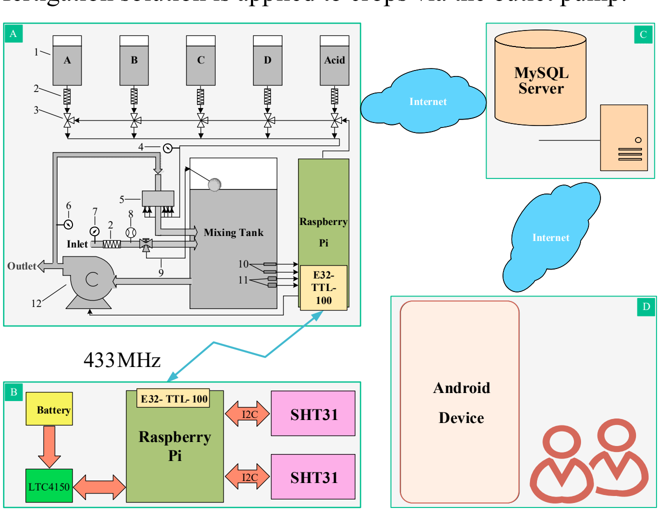


Fig. 1. Block diagram of greenhouse remote control system

The hardware circuit block diagram of the greenhouse control system is shown in Figure 2. The whole hardware circuit can be divided into three sub-circuits (e, f, g) according to the power supply voltage, e with 5V DC power supply, f with 24V current supply, and g with 380V AC power supply for driving the water pump. Each sub-circuit is isolated by a relay. In Figure 2, “1” is the self-designed EC sensor (Wu et al., 2019), and “2” is the pH sensor purchased from Telesky Company with an accuracy of <=0.01. Other parts are also shown in Figure2. The controller reads the value of the EC/pH sensor through the GPIO interface and controls the solenoid valve and AC contactor through I2C protocol.

2.3 Greenhouse environmental monitoring system

As shown in Figure 1(B), we used a DC 5V power bank as power supply and a LTC4150 Coulomb Counting Module to monitor power consumption. The module generated an interrupt once the 0.0001707Ah current passed through the sensor module(Loukatos et al., 2018). The subsystem B read the value of SHT31 temperature and humidity sensor through I^2C and uploaded the data along with power consumption data in real time to the subsystem A through E32-TTL-100 LoRa module, and finally uploaded them to MySQL database and Android software. The E32-TTL-100, which was purchased from Chengdu Ebyte Electronic Technology Co., Ltd, uses the SX1278 RF chip with a transmission frequency of 433MHz and a communication distance of up to 3000 m (E32-TTL-1W, 2019). Since the system is portable and abandons a lot of work on the field wiring, it is suitable to greenhouse applications.

The block diagram of the system hardware connection is shown in Figure 3. The system is connected with two SHT31 temperature and humidity sensors. Since the Raspberry Pi has a total of 40 GPIO interfaces, more sensors such as CO_2 sensors and radiative sensors can be installed in the future. The power bank uses Xiaomi-3 series with an output of 5V 2.4A. The LTC4150 Coulomb count is produced by Shenzhen Youxin Electronic Technology Co., Ltd. The SHT31 sensor is produced by Telesky, with SHT31 sensor chip (Sensirion Company, Swiss).

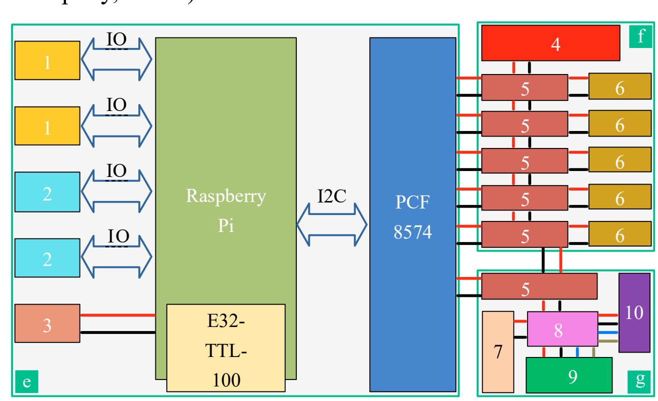


Fig 2 circuit block diagram of fertigation system
1 EC sensor, 2 pH sensor, 3 5V DC power supply, 4 24V DC power supply, 5 5V DC relay, 6 24V DC solenoid valve, 7 220V AC power supply, 8 24V DC relay, 9 380 AC power supply, 10 220V AC contactor

2.4 MySQL remote database

The database was designed using star topology. As shown in Figure 3, different user information tables were created for different users to store information about the greenhouse environment, including control parameters, such as fertilizer ratio, fertigation schedule, etc. and greenhouse environmental information, such as temperature and humidity data, etc. Users with an Android device can communicate with subsystem A through the MySQL database server remotely.

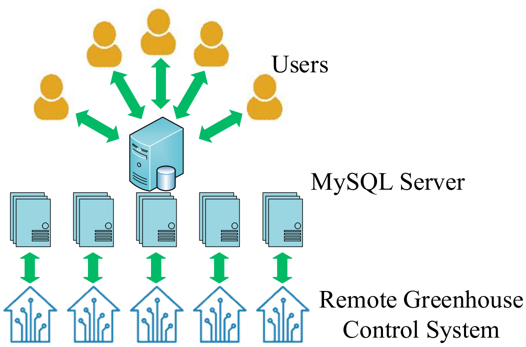


Fig.3 Block diagram of MySQL Server

2.5 Android software

The android monitoring software is written in Java by using Android Studio 3.2.1 (Android Studio, 2019), which is the official Integrated Development Environment (IDE) for Android app development, based on IntelliJ IDEA (IntelliJ IDEA, 2019). The software had a built-in SQLite database, which was a small, fast, self-contained, highly reliable, full-featured SQL database engine. It is the most used database engine in the world and is built into all mobile phones and most computers (SQLite library, 2019).

The Android monitoring software, which can display the greenhouse information in real time including air temperature and humidity, EC/pH value of fertigation solution, etc., communicates with the subsystem A through the MySQL database server. The software provides users with friendly human-computer interaction, with which users can operate the fertigation more efficiently. In the future, after collecting much more information about the greenhouse environment such as illumination intensity, CO_2 concentration, the precision greenhouse management can be carried out. For example, we can use Big Data analysis, machine learning to open or close the sunroof automatically, and supplement CO_2 gas fertilizer to achieve fully automatic production.

3. RESULTS AND DISCUSSION

3.1 Experiment analysis of the greenhouse control System

After the system was developed, the EC and pH response during the fertigation procedure of the greenhouse control system were tested. The experiment was conducted on May 15, 2019 in No. 7 solar greenhouse of Zhuozhou Experimental Station of China Agricultural University. Before the start of the experiment, the four tanks of A, B, C and D were respectively filled with 337.27g/L $Ca(NO_3)_2{\cdot}4H2O$ stock solution, 134.18g/L NaH_2PO_4 stock solution, 89.23g/L K_2SO_4 stock solution and 200.00 g/L $MgSO_4$ stock solution, as such the concentration of N, P, K and Mg elements in each tank were the same, 40g/L. Acid bucket was filled with 1.0 mol/L dilute nitric acid, and the inlet water was tap water (EC= 0.36 mS/cm, pH = 7.5). The power of the output pump is 4.0 kW, with a rated flow of 25 m^3/h, and a head of 32m. The fertilizer ratio was set to A: B: C: D = 4:3:2:1 from the Android monitoring software. The EC target value was set to 2.0 mS/cm, and the pH target value was set to 5.5. The EC and pH value of the fertigation solution in the mixing tank are read every 2 seconds after the system starts running. The response of the EC/pH value over time is shown in Figure 4 and Figure 5, and the error data is shown in Table 1.

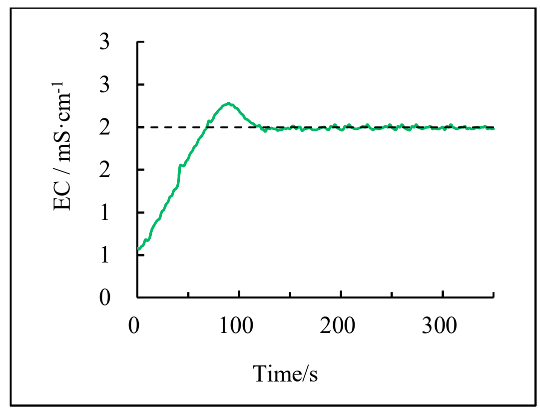


Fig.4 EC response over time

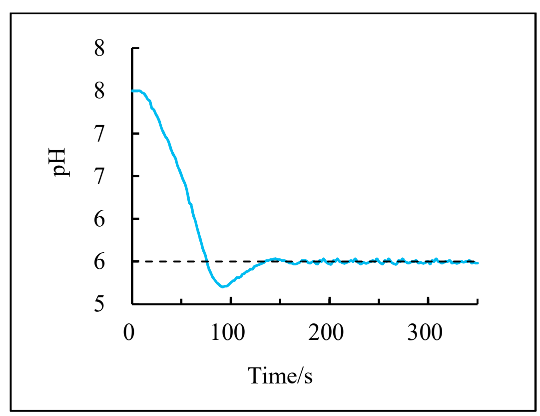


Fig. 5. pH response over time

Table 1. Results of EC/pH control

	Set value	Response time	Max overshoot	Overshoot ratio
EC	2.0 mS/cm	148 s	0.28 mS/cm	14%
pH	5.5	158 s	0.27	4.9%

The results showed that the EC/pH value in the mixing tank can reach the set value in about 150 seconds. The maximum overshoot of EC value is 0.28 mS/cm with an overshoot ratio of 14%. The pH value response is ideal, with a maximum overshoot of 0.27 and an overshoot ratio of 4.9%. Therefore, the integrated greenhouse control system developed can basically meet the intelligent management requirements of greenhouse fertigation.

3.2 Experimental analysis of greenhouse environmental monitoring system

The greenhouse environmental monitoring system was developed based on LoRa wireless communication technology. LoRa (Long Range) is a kind of chirp spread spectrum (CSS) technology and the first low-cost implementation of chirp spread spectrum for commercial usage. It was developed by Cycleo Company (Grenoble, France) and bought by Semtech Company (Rapperswil, Switzerland) in 2012, a founding member of the LoRa Alliance (LoRa, 2019). The E32-TTL-100 used in the system is a LoRa module based on the SX1278 RF chip (Semetch). The related parameters are shown in Table 2.

Table 2. E32-TTL-100 Performance parameter (E32-TTL-1W, 2019)

RF parameters	Value	Remarks
Working Frequency	410~441 MHz	433MHz (default)
Transmit Power	10~20 dBm	20dBm（~100mW）(default)
Transmit Rate	0.3k~19.2 kbps	2.4kbps (default)
Transmission Distance	3000 m	Test in a sunny and open environment, with antenna gain of 5dBi, height of 2m, transmit rate of 2.4kbps

The E32-TTL-100 has four operating modes, namely normal mode (mode 0), wake mode (mode 1), power saving mode (mode 2), and sleep mode (mode 3). In the experiment, the greenhouse environmental monitoring system sends the collected temperature and humidity data to the subsystem A through the E32-TTL-100 module and finally uploads it to the MySQL database and Android mobile device through the wireless network. Therefore, subsystem A is the receiver, and the subsystem B is the transmitter. According to the working mode characteristics of the E32-TTL-100 module (E32-TTL-1W, 2019), the receiver and the transmitter can have five combinations, as shown in Table 3.

Table 3. Combination mode of the receiver and transmitter

Combination mode	receiver	transmitter
1	Mode 0	Mode 0
2	Mode 0	Mode 1
3	Mode 1	Mode 0
4	Mode 1	Mode 1
5	Mode 2	Mode 1

The transmitter communicated with the receiver under the five combined modes with different communication distance. Test result showed that the effective distance of data communication is about 2800 m. And then under the five combined modes, the reliability and power consumption of the communication data are also tested respectively with a fixed communication distance of 1000 m. The power consumption is measured by the LTC4150 coulomb counter. The sampling period of temperature and humidity is 2 seconds, and the wireless transmission period is 30s. The experiment was conducted continuously over 12 hours in outdoor space of an experimental solar greenhouse in Zhuozhou Experimental Station of China Agricultural University on May 15, 2019. The results are shown in Table 4.

Table 4. Test results of the greenhouse monitoring system under different conditions

Combination mode	Packet loss ratio / %	Power consumption / W
1	0.155	2.320
2	0.155	2.305
3	0.155	2.290
4	0.156	2.270
5	0.157	2.250

The results showed that the packet loss ratio is 0.15% - 0.16%, which means that the communication is reliable. The system power consumption is the lowest under the combination mode 5, which is 2.25 W, but the packet loss ratio is relatively high. User can choose a combination mode with a lower power consumption according to the test results. Since the power consumption for the LoRa wireless transmission was relatively low within 100mW, the main power consumption of the greenhouse environmental monitoring system was from the controller Raspberry Pi. The controller power consumption can be further decreased by closing part of the peripheral interface of the Raspberry Pi (such as HDMI, USB, etc.), or replacing Raspberry Pi with other lower power controllers, such as ESP-WROOM-02 Wi-Fi module (ESP8266 WROOM Series, 2019).

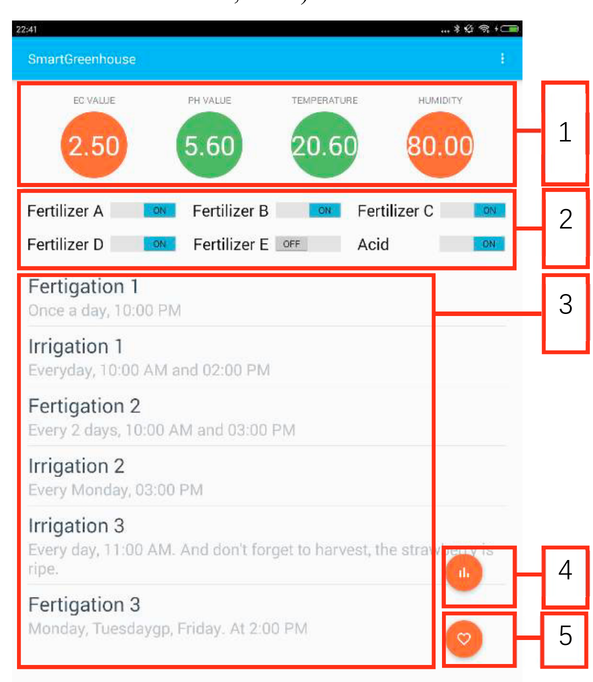


Fig. 6 Main interface of the Android software

3.3 Android monitoring software

The main functions of the Android software are shown in Figure 6, Figure 7 and Figure 8. Users can remotely view greenhouse environment information (such as temperature and humidity data) and control the greenhouse fertigation in real time. In the future, more sensors (such as light sensors, CO_2 sensors, etc.) can be equipped to achieve full-scale automated management of the greenhouse, which will greatly increase the management efficiency for farmers.

The main interface of the Android monitoring software was shown in Figure 6 where “1” indicates the EC/pH value of the fertigation solution in the mixing tank and the air temperature and humidity in the greenhouse, “2” is the switches for the 4 fertilizers tanks (A, B, C and D) and the acid tank, “3” is the recent fertigation plan. The Historical Data interface can be come out by tapping “4”, and the Fertigation Setting interface can be added or deleted by tapping “5” (the heart-shaped buttons).

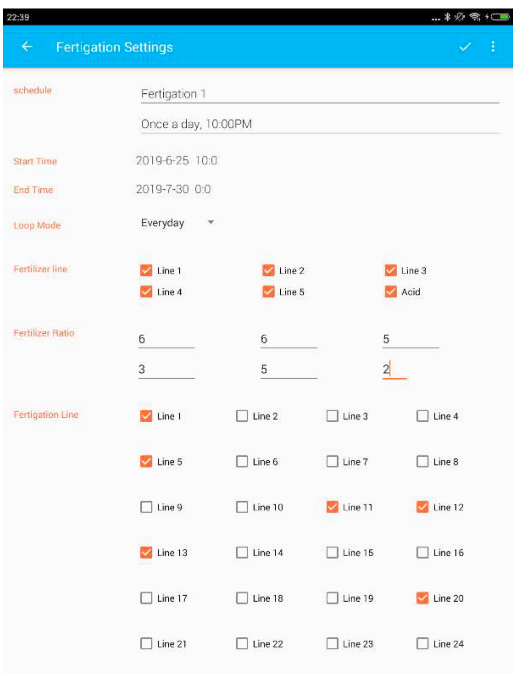
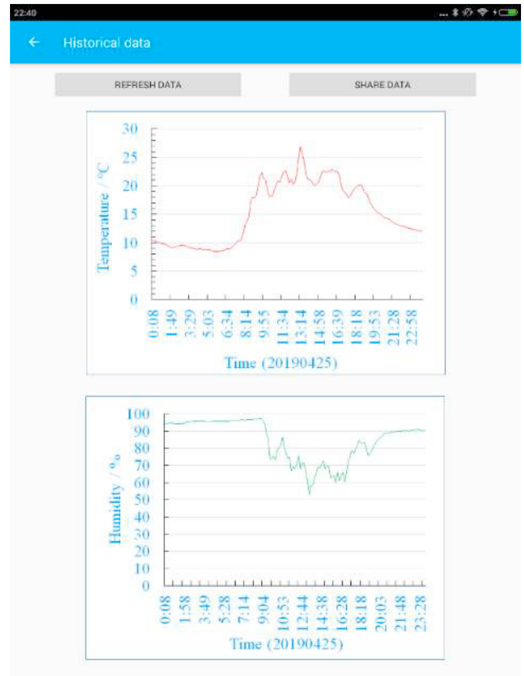


Fig. 7 Fertigation Setting interface of the Android software

Figure 7 showed the fertigation setting interface, where the Name, Start Time, End Time, Loop Mode (such as every day, every 5 days, etc.), Fertilizer Line option, Fertilizer Ratio and Fertigation Line option can be set. After settings are saved, they will be synchronized to the greenhouse control system, and the system will automatically perform fertigation according to the schedule.

Historical Data interface was shown in Figure 8. By tapping “REFRESH DATA” button in the upper left corner of the interface, user can check the air temperature and humidity data of the past day. By tapping the “SHARE DTA” button a CSV file of the temperature and humidity will be automatically generated and shared to friends through social software such as WeChat, which greatly improves the efficiency of data usage.



(a) Curve of humidity data

(b) Social software for data sharing

Fig. 8 Historical Data interface of the Android software

4. CONCLUSSION

A remote-control system for greenhouse environment based on open source software and hardware was developed for real-time monitoring of temperature and humidity in the greenhouse and automatic management of fertigation, which will provide efficient technical support for the automatic production of greenhouses.

(1) The developed greenhouse control system has a good performance to meet the requirements of greenhouse fertigation. It provides technical basis for future greenhouse model construction and Big Data analysis, such as establishing a model between environmental information and crop fertigation demand based on environmental data in the greenhouse. More experiments will be conducted to verify the performance of the system regarding crop needs.

(2) The greenhouse environment monitoring system is developed based on LoRa technology, which has the advantages of low-power consumption and long-distance transmission. In the future, with further lower power consumption, a large-scale portable greenhouse wireless sensor network can be implemented, enabling a smart greenhouse.

(3) In addition, an Android monitoring software with a friendly human-computer interaction was developed for remote management of the greenhouse. With the Android software, the user can set the corresponding control strategy according to the environmental information in the current greenhouse. More effort will be put into the index development related to alerts, such as thresholds to irrigate according to the temperature and solar radiation in the greenhouse, which will be smarter and very helpful to the farmers.

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