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# Development of Smart Stirred Machine for Vinegar Solid-State Fermentation Using Embedded System and Cloud Computing Server

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## Abstract

Through the analysis of the functional requirements and working schedule of the grains-stirring machine, an intelligent system has been developed for solid-state fermentation in this paper. Firstly, the embedded system for stirred machine is designed, which includes power-supply module, motor-derived circuit, proximity sensor, temperature sensor, 2.4G wireless and GPRS module etc. Then, a cloud computing server platform is presented to monitor the working process and the quality of fermentation. The communication between the cloud computing server and stirred machine is GPRS. The experimental result demonstrates the performance of the developed system. Furthermore, the system increased the automatic cleaning and crushed-material design, avoids caking and over-fermentation, and improves the efficiency and quality of stirred vinegar cultural.

## Keywords

Grains-Stirring, STM32, Intelligent Control, Cloud Computing Server

## 1. Introduction

Vinegar is an essential condiment in the food industry and is a typical product made from the solid-state fermentation [1]. However, the traditional fermentation process relies on workers' subjective experience to stir grains and make acid production rates vary considerably. Acid yield is one of the crucial indexes to evaluate the fermentation quality of fermented grains [2]. How to increase the rate of acid production is a complicated issue in the vinegar brewing industry.

At present, the research on the vinegar brewing industry mainly focuses on the separation of acetic acid bacteria [3], the development of new vinegar [4] and the metabolites in the solid-state fermentation process [5]. However, few studies have been done to improve the acidogenicity of balsamic vinegar, and there is a lack of in-depth understanding in this respect.

In the solid-state fermentation, stirring grains is a very crucial step. On the one hand, the lower alcoholic fermentation product is thoroughly mixed with the upper vinegar sauce, and the cultivation of microorganisms such as acetic acid bacteria is expanded. On the other hand, by stirring grains to reduce the temperature and oxygen supplement to ensure the growth activity of acetic acid bacteria and other microorganisms [6]. According to the study of acetic acid bacteria group, the most active metabolism is at 38°C ~ 45°C [7]. The high fermented temperature will affect the growth and metabolism. It is found that the temperature of the stable fermentation stage can be controlled to increase the metabolic activity of acetic acid bacteria and other microorganisms [8].

However, in the traditional process of stirring grains, the time of stirring grains and the stirring grains depth are judged according to the subjective experience of the workers. This sensory control lacks a scientific basis, making it difficult to guarantee the quality of the vinegar produced. In addition, according to the field investigation in the production workshop, it was found that there was a caking problem in the vinegar during the fermentation process, and the problem would affect the quality of the vinegar to a certain extent.

This experiment by keeping the original traditional craft, through the online temperature monitoring technology to monitor the temperature in the fermentation process of vinegar. Then the time and frequency of stirring grains are determined based on the temperature, automatically adjust stir fermented grains process parameters to control the temperature of the fermentation stage, making the stirring grains toward the intelligent direction. At the same time, two essential fermentation indexes (total acid content and non-volatile acid content) compared with the traditional process, to improve the acid yield of vinegar.

# 2. System Design

## 2.1. System Structure

According to design requirements of the system, an intelligent control system of grains-stirring machines is designed with the STM32 Microcontroller as its core. This system is constituted by two independent control units, namely a temperature monitoring device and an executive device of grains stirring. The temperature monitoring device sends manipulated instructions (relating to time and depth of grains stirring) by measured temperature values of fermenting tanks. Then, these instructions are transferred to the executive device of grains stirring via 2.4G modules, so that the supervisory device of grains stirring can be controlled to conduct automatic grains stirring and vibration of crushed material, etc. Also, each measured temperature value will be sent to a cloud computing platform via the GPRS module of the temperature monitoring station to provide a reference for optimization of fermentation conditions further. Figure 1 and Figure 2 show the system structure.

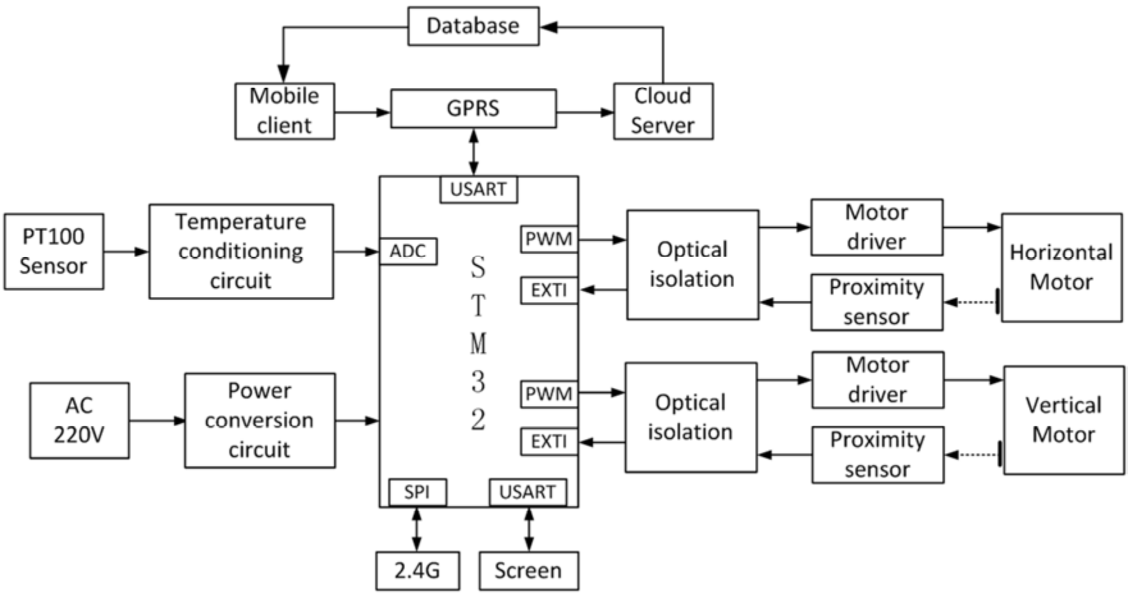


***Figure 1.*** *System structure of temperature monitoring device.*

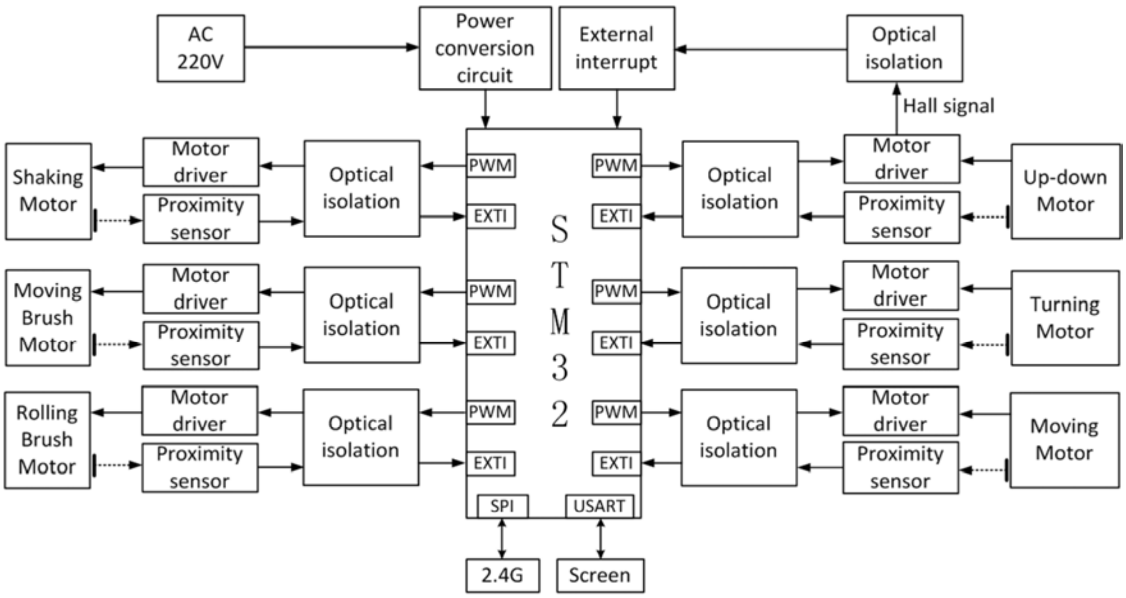


***Figure 2.*** *The system structure of the executive device of grains stirring.*

### 2.2. Hardware Design

The hardware part is mainly composed of MCU, Power-supply module, a motor drive circuit, proximity sensor circuit, temperature sensor circuit, 2.4G Wireless RF module, GPRS module, industrial touchscreen module.

#### 2.2.1. MCU Module

A STM32F103ZET6 microcontroller was used as the MCU, which consist of 64 Kbytes SRAM, 512 Kbytes Flash memory, 32 kHz oscillator, 3×12-bit A/D converters, 2×12-bit D/A converters, Debug mode, 112 fast I/O ports, 11 timers, 5 USARTs, 2 SPIs (18 Mbit/s) and so on. The microcontroller is maken by the Cortex-M3 framework, which is high performance, low cost and low power consumption [9].

#### 2.2.2. Power-supply Module

Different modules need different power-supply, and a voltage conversion framework was proposed to realize this target. The input voltage of the switching circuit is 24V. An SYSY20-24S±12 chip was used to convert 24V into ±12V, where the positive voltage was supplied for the serial-port screen, the negative voltage was a supply for the circuit of temperature conditioning. An LM2576-5V chip was utilized to convert 24V into 5V for the GPRS module. An LM2576-3.3V chip is used to transform to 3.3 V for the 2.4G wireless module. Proximity sensors and BLDCM drivers were connected to 24V switching power supply respectively. In the design of power-supply modules, not only need to consider the necessary parameters of current capacity and voltage range, but also consider the power conversion efficiency, anti-interference and other factors [10].

Figure 3 shows the circuit of the external power source, where an LM2576-5V chip was utilized to convert 24V into 5V for the GPRS module.

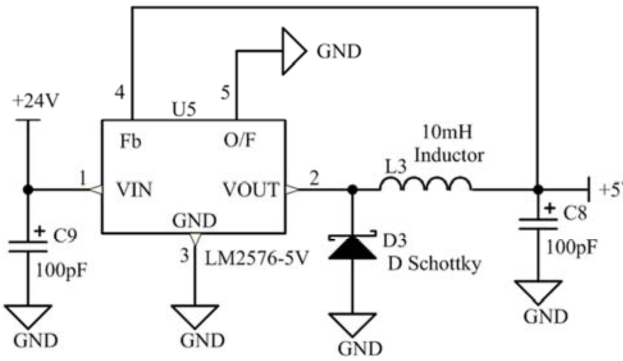


*Figure 3. Circuit of external power source.*

Figure 4 shows the circuit of the internal power source, where an SYSY20-24S±12 chip was used to convert 24V into ±12V double voltage. The positive voltage was supplied to the serial-port touchscreen, while the negative voltage was for the circuit of temperature conditioning.

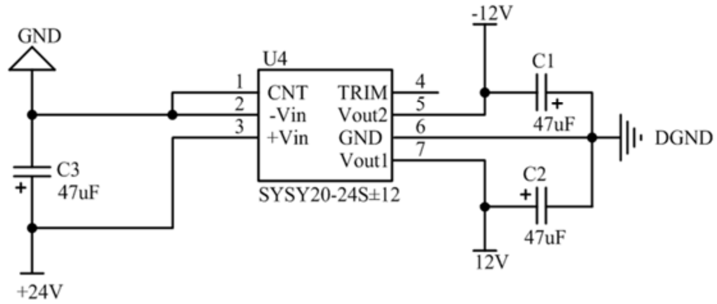


*Figure 4. Circuit of internal power source.*

Figure 5 shows the circuit of 3.3V voltage conversion, where 12V was converted into 3.3V with an LM2576-3.3V chip for power supply of 2.4G modules.

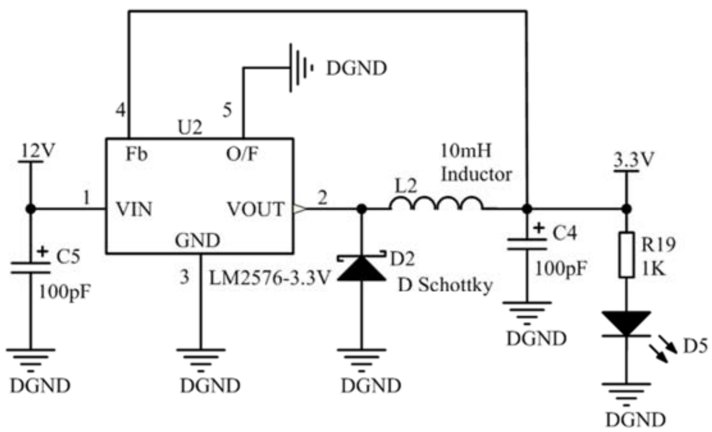


*Figure 5. Circuit of 3.3V voltage conversion.*

### 2.2.3. Circuits of Motor Drive

Brushless Direct Current Motors (BLDCM) was used in this system, which is a stable operation, easy maintenance, high operational efficiency and excellent performance of speed [11]. According to different requirement, 750W, 1000W and 1500W motors were used in various parts. One example of motor driving circuit is shown in Figure 6. The motor steering and enabling are controlled by the TTL-high level and TTL-low level from the port PB9. The direction of rotation is manipulated by TTL-high level and TTL-low level from the port PB8. The velocity of motor is controlled by PWM signal from the port PC8. The HALL singal is sent out to the port PF9. Finally, to achieve smooth and stable speed regulation of motors, PID algorithm was used to adjust the ratios of PWM.

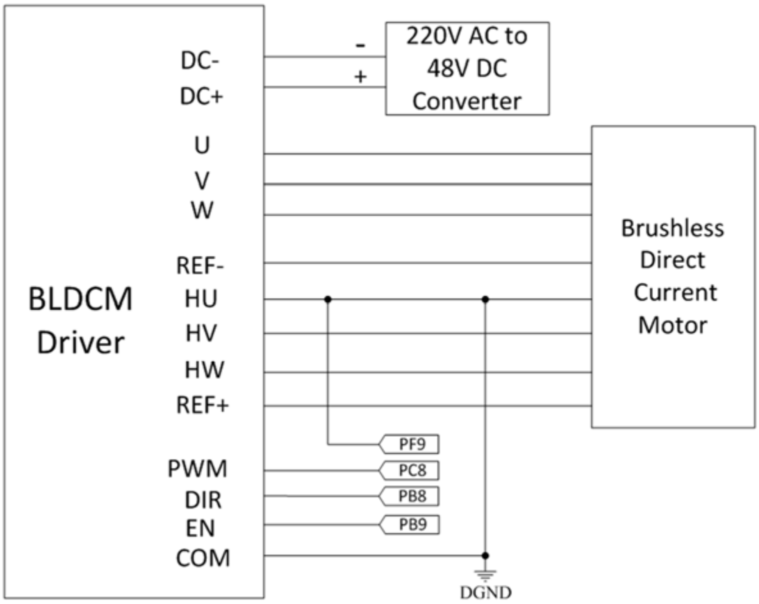


***Figure 6.*** *Circuits of motor drive.*

### 2.2.4. Circuits of Proximity Sensor

The LJ12A3-4-Z/BX sensor, an NPN inductive proximity sensor, is used in this system. Figure 7 shows a circuit connecting a proximity sensor with an STM32 Microcontroller (where one of the sensors is taken as an example). To avoid signal interference, in the interface circuit, a TLP521 optoisolator was added between the sensor and the external interrupt port of STM32 [12]. The operating principle of this circuit is: when a magnetic object is getting close to or moving away from the circuit, MCU and its corresponding interrupt port are triggered and MCU immediately performs the next operation by received interrupt signals.

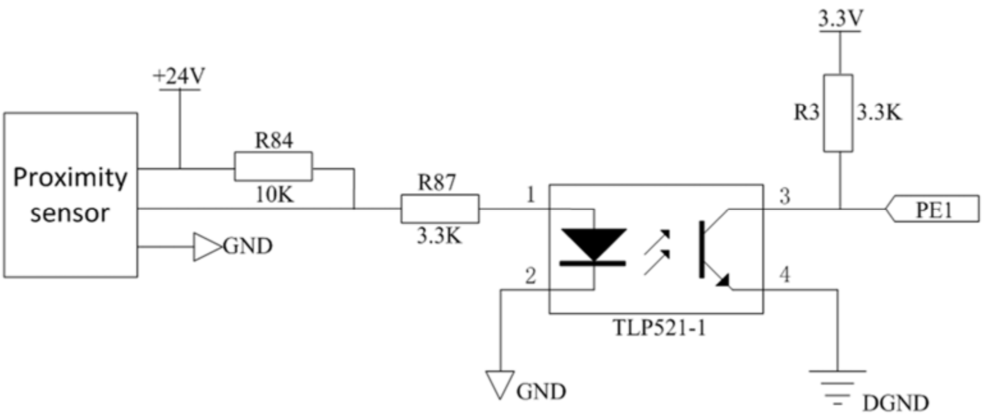


***Figure 7.*** *Circuits of proximity sensor.*

### 2.2.5. Circuits of Temperature Sensor

The core of temperature monitoring is temperature measurement, and its measurement accuracy is directly related to the reliability of the system. Therefore, the system was designed to use Three-wire platinum RTD pt100 as its temperature sensor, which is characterized by high accuracy, excellent stability, and simple circuit design.

The system was designed to measure temperature values at nine depths of grains in a fermenting tank (i.e. nine Pt100s were applied). One of PT100 signal adjustment circuit is shown in Figure 8. The change of PT100's resistance is coverted into electrical signal via a bridge circuit firstly, Then, the electrical signal is adjusted into the standard signal required by MCU through the amplified curicuit [13]. As the primary control chip has an I/O interface for A/D switching, an A/D switching circuit is not necessary.

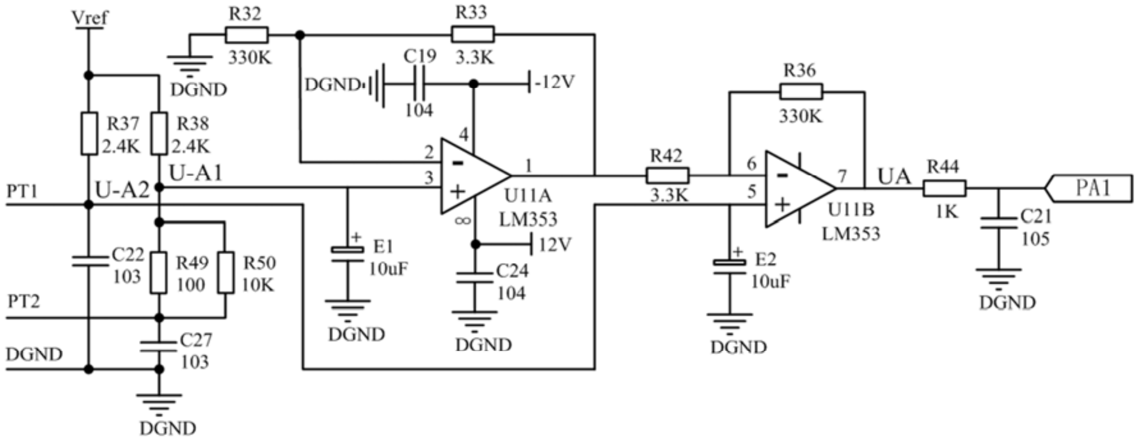


***Figure 8.*** *Circuits of temperature sensor.*

Shown in Figure 8, the gain of the amplifier is:

$$G_v = \frac{R36 + R42}{R42} = 101 \tag{1}$$

### 2.2.6. 2.4G Wireless RF Module

The Nordic Company produces the nRF24L01 module. Due to the substantial capacity of resisting disturbance, nRF24L01 is especially suitable for industrial control. In a DIP-8 standard encapsulation mode, the nRF24L01 wireless-transmission module can be directly inserted into the reserved connector of a circuit. As for its data communication, the SPI protocol, proposed by the Motorola Company, is adopted. According to the official manual, the main control chip supports two SPI interfaces: SPI1 and SPI2. The designer chose to use SPI1. As a result, in pin connections, SPI Clock pin (SCK), SPI Slave Data Output pin (MISO) and SPI Slave Data Input pin (MOSI) were connected to PA5, PA6, and PA7 of the microcontroller respectively. Chip Enable pin (CE) was connected with PB6, SPI Chip Select pin (CSN) with PB7 and Interrupt Request pin (IRQ) with PA0. In this way, users can switch nRF24L01 into a receiving mode or a sending mode with MCU, where MCU can identify received data by observing its IRQ pin.

### 2.2.7. Circuits of GPRS Module

The communication chip in this system is SIM900A produced by SIMCom. It is a dual-frequency GSM/GPRS module in an SMT encapsulation mode and featured by stable performance, elegant appearance, high-cost performance, and satisfaction of users' multiple needs.

Figure 9 shows the connection of SIM900A and MCU, level conversion chip MAX232 between MCU and SIM900A. The AT instruction is a communication protocol between MCU and SIM900A and ensures smooth sending and receiving of messages and data transmission [14].

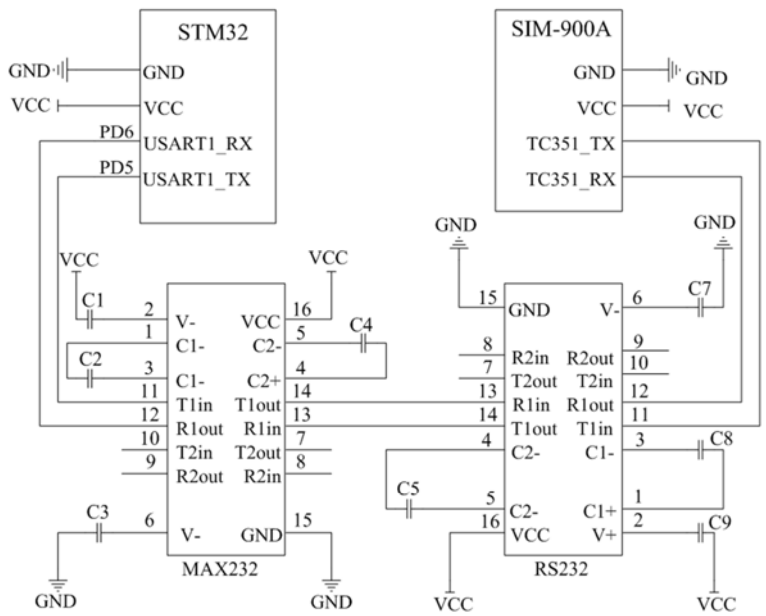


***Figure 9.*** *Circuits of GPRS module.*

### 2.2.8. Circuits of the Serial-port Touchscreen

DMT10600T102_02W produced by Beijing Dewin Technology Co., Ltd was used as the touchscreen in this system. The touchscreen is connected to the ARM via an interface circuit (shown in Figure 10). In this interface circuit, MAX232 was used to convert the TTL/CMOS logic levels to RS232 logic levels. A user can set up instruction by the communication protocol and realize data communication between the screen and ARM by the mode of serial port communication. ARM sets up and tests the production process by receiving instructions from the screen via the RXD serial port line; and carries out information display by sending instructions to the screen via the RXD serial port line.

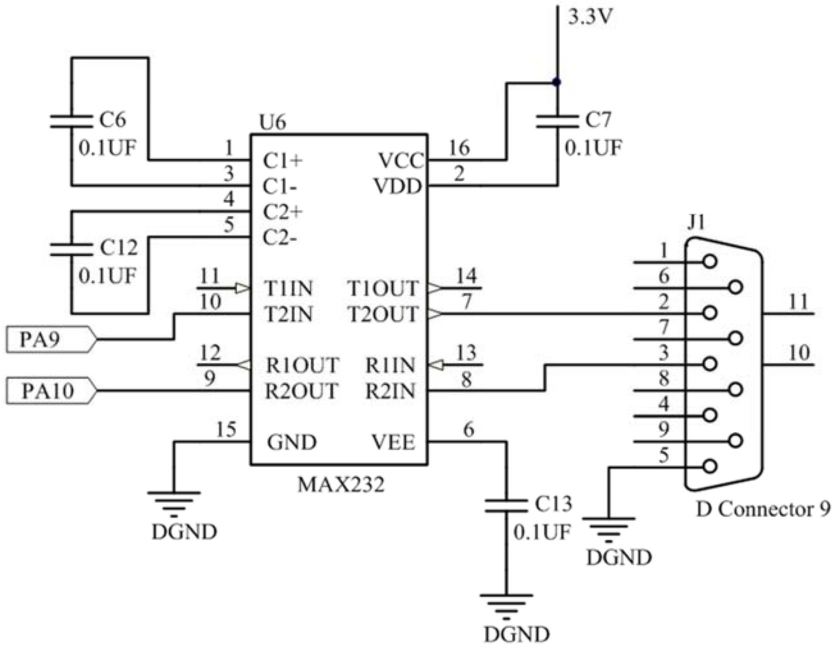


***Figure 10.*** *Circuits of the serial-port screen.*

### 2.3. Establishment of the Cloud Computing Server

In this project, a cloud computing server platform based on Tencent Cloud was used. Cloud Virtual Machine (CVM) is a cloud virtual machine with high performance and stability and can provide secure, reliable and adjustable computing services. This server is a standard S1 server with 1core, 1GB and 1Mbps applied to the primary network.

This project adopted a monitoring method of vinegar fermentation temperatures by a cloud computing server. The cloud computing server mainly includes three parts: a socket communication server, an MSSQL database, and web clients.

The interface of Socket communication server as shown in Figure 11, it is an application program with some communication functions, created with C# as its development language, in the development environment of Visual Studio. Its main features include receiving, testing and processing of temperature data from MCU and data sending to the MSSQL database for data usage of clients.

As shown in Figure 12, it is a SQL Server for Microsoft and a database platform offering a complete solution from the server to the client and high-performance data access. Its database server is a database management system for database establishment, usage, and maintenance. In this project, the MSSQL database was used to ensure stable and reliable data storage for data transfer by clients.

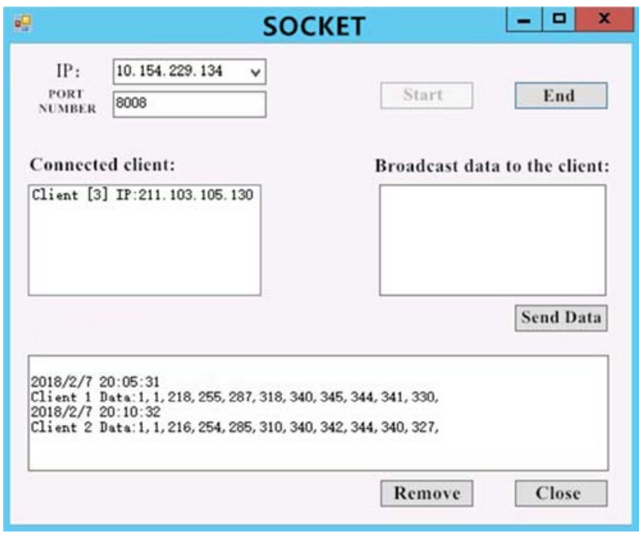


***Figure 11.*** *The interface of Socket communication server.*

10_154_229_134.s...tank1 - dbo.test1

| DateTime | Depart | TankNum | Temp1 | Temp2 | Temp3 | Temp4 | Temp5 | Temp6 | Temp7 | Temp8 | Temp9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017-12-05 12:47:00 | 1 | 1 | 35.5 | 36.1 | 35.2 | 35.0 | 35.0 | 34.5 | 33.9 | 32.2 | 29.8 |
| 2017-12-05 12:57:00 | 1 | 1 | 35.5 | 36.2 | 35.3 | 35.0 | 35.1 | 34.6 | 33.9 | 32.2 | 29.7 |
| 2017-12-05 13:07:00 | 1 | 1 | 35.6 | 36.2 | 35.4 | 35.1 | 35.1 | 34.6 | 33.9 | 32.2 | 29.6 |
| 2017-12-05 13:17:00 | 1 | 1 | 35.6 | 36.2 | 35.4 | 35.2 | 35.2 | 34.6 | 33.9 | 32.2 | 29.5 |
| 2017-12-05 13:27:00 | 1 | 1 | 35.6 | 36.2 | 35.5 | 35.2 | 35.2 | 34.6 | 33.9 | 32.2 | 29.4 |
| 2017-12-05 13:37:00 | 1 | 1 | 35.6 | 36.3 | 35.5 | 35.3 | 35.3 | 34.6 | 33.9 | 32.1 | 29.3 |
| 2017-12-05 13:47:00 | 1 | 1 | 35.5 | 36.3 | 35.5 | 35.3 | 35.3 | 34.7 | 33.9 | 32.1 | 29.2 |
| 2017-12-05 13:57:00 | 1 | 1 | 35.5 | 36.3 | 35.5 | 35.4 | 35.3 | 34.7 | 33.9 | 32.1 | 29.1 |
| 2017-12-05 14:07:00 | 1 | 1 | 35.5 | 36.3 | 35.5 | 35.4 | 35.4 | 34.7 | 33.9 | 32.1 | 29.0 |
| 2017-12-05 14:17:00 | 1 | 1 | 35.5 | 36.3 | 35.6 | 35.5 | 35.4 | 34.7 | 34.0 | 32.0 | 28.9 |
| 2017-12-05 14:27:00 | 1 | 1 | 35.5 | 36.3 | 35.6 | 35.5 | 35.5 | 34.7 | 34.0 | 32.0 | 28.8 |
| 2017-12-05 14:37:00 | 1 | 1 | 35.5 | 36.3 | 35.6 | 35.6 | 35.5 | 34.8 | 34.0 | 32.0 | 28.7 |
| 2017-12-05 14:47:00 | 1 | 1 | 35.5 | 36.3 | 35.6 | 35.6 | 35.6 | 34.8 | 34.0 | 32.0 | 28.6 |
| 2017-12-05 14:57:00 | 1 | 1 | 35.5 | 36.3 | 35.6 | 35.7 | 35.6 | 34.8 | 34.1 | 32.0 | 28.6 |
| 2017-12-05 15:07:00 | 1 | 1 | 35.5 | 36.3 | 35.7 | 35.7 | 35.6 | 34.9 | 34.1 | 31.9 | 28.5 |
| 2017-12-05 15:17:00 | 1 | 1 | 35.4 | 36.3 | 35.7 | 35.7 | 35.7 | 34.9 | 34.1 | 31.9 | 28.4 |
| 2017-12-05 15:27:00 | 1 | 1 | 35.4 | 36.3 | 35.7 | 35.8 | 35.7 | 34.9 | 34.1 | 31.9 | 28.3 |
| 2017-12-05 15:37:00 | 1 | 1 | 35.4 | 36.3 | 35.7 | 35.8 | 35.8 | 35.0 | 34.1 | 31.9 | 28.3 |
| 2017-12-05 15:47:00 | 1 | 1 | 35.4 | 36.3 | 35.7 | 35.8 | 35.8 | 35.0 | 34.2 | 31.9 | 28.2 |
| 2017-12-05 15:57:00 | 1 | 1 | 35.4 | 36.3 | 35.7 | 35.9 | 35.8 | 35.0 | 34.2 | 31.9 | 28.1 |
| 2017-12-05 16:07:00 | 1 | 1 | 35.4 | 36.3 | 35.8 | 35.9 | 35.9 | 35.1 | 34.2 | 31.8 | 28.1 |
| 2017-12-05 16:17:00 | 1 | 1 | 35.3 | 36.3 | 35.8 | 35.9 | 35.9 | 35.1 | 34.2 | 31.8 | 28.0 |
| 2017-12-05 16:27:00 | 1 | 1 | 35.3 | 36.3 | 35.8 | 36.0 | 36.0 | 35.1 | 34.2 | 31.8 | 27.9 |
| [illegible] | 1 | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

1 / 1797

***Figure 12.*** *The interface of MSSQL database.*

Web clients include a mobile client (APP) and a webpage client. The mobile client (APP) is shown in Figure 13. The APP interface is divided into a monitoring interface and a control interface. The monitoring interface consists of blocks of information, display of temperature data, temperature profile and real-time query of history. A user can obtain temperature data easily by selecting conditions such as a serial number. The control interface carries out remote control of the temperature measuring device for cloud-node fermentation tanks. After a user presses a control command, the signal will be sent to a cloud-node fermentation tank via the cloud-computing management platform to conduct motion control of the device. As a result, workers can monitor the temperature of cloud-node fermentation tank and control the device outside the site.

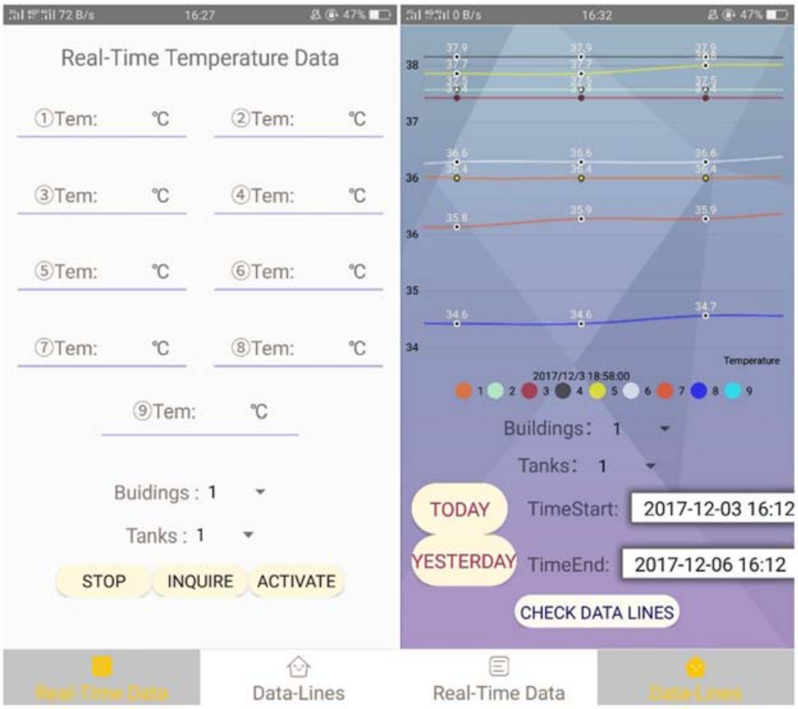


***Figure 13.*** *The interface of mobile client.*

The webpage client is shown in Figure 14. It is a cloud computing monitoring system of vinegar fermentation temperatures by B/C structure. In any device, such as a cell phone and a computer with or without the APP, connecting with the Internet, real-time on-line monitoring of vinegar fermentation temperatures can be conducted by entering the correct IP address on a browser. Thus, these two clients achieve perfect mutual complementation in respect of the cloud computing monitoring system of stable fermentation temperatures, which helps workers monitor the temperature data, devise a scientific and efficient fermentation scheme and enhance output and quality of fermentation.

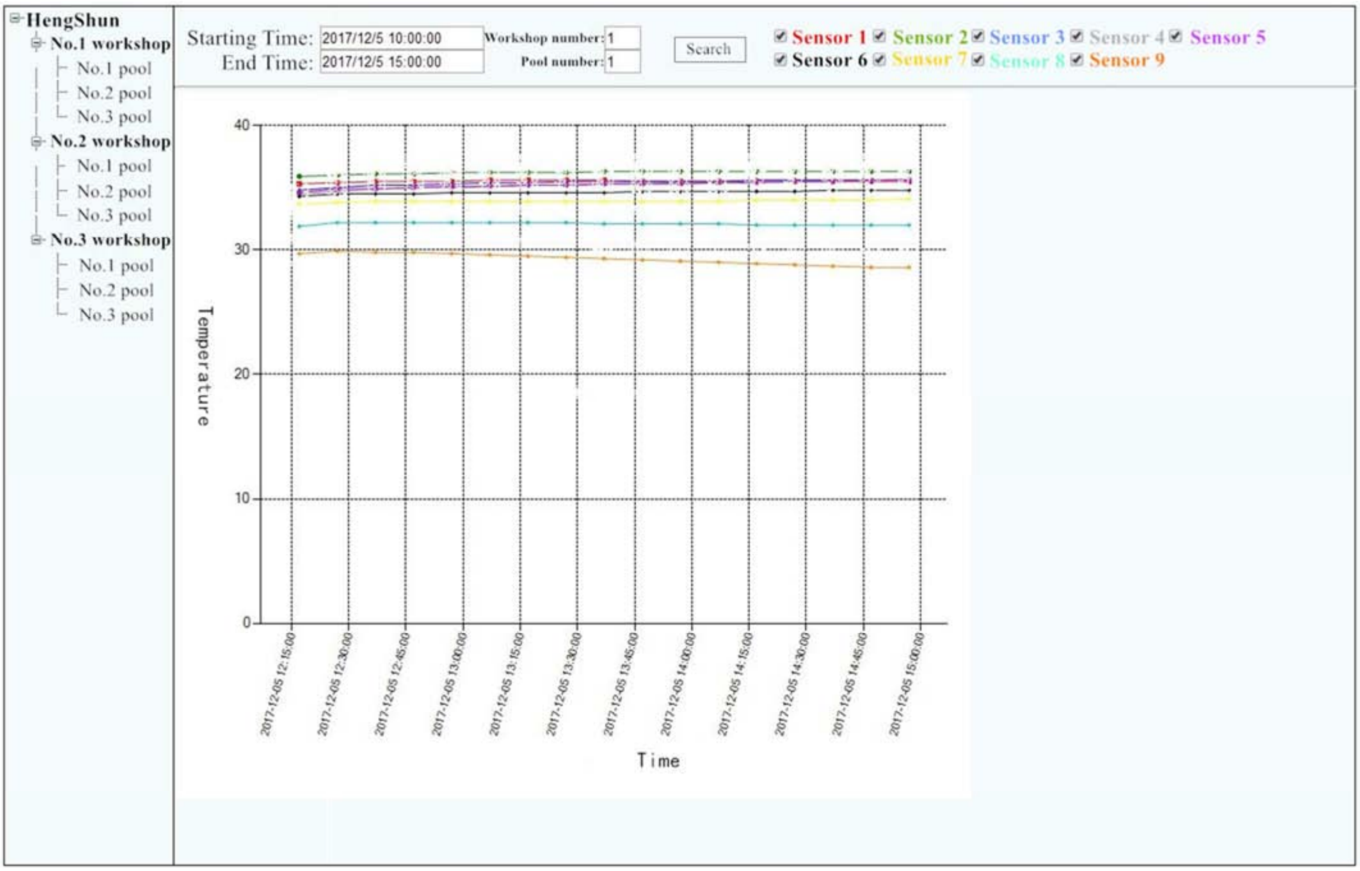


***Figure 14.*** *The interface of webpage client.*

## 3. System Test

The test focuses on accuracy of temperature measurement, layering accuracy and quality of vinegar.

The core of temperature monitoring is temperature measurement, and its measurement accuracy is directly related to the reliability of the system. The professional equipment is taken to test the accuracy for comparison. For temperature measurement, TTM59 digital thermometer produced by Cooper-Atkins was used in the test. As shown in Table 1, the accuracy of the developed system was high enough.

***Table 1.*** *Comparison between two devices.*

| Items | System Collece (AVG)/°C | Equipmen Collect (AVG)/℃ | Error/°C | Relative error |
|---|---|---|---|---|
| Group 1 | 22.1 | 23.0 | 0.1 | 0.43% |
| Group 2 | 47.3 | 47.0 | 0.3 | 0.64% |

Free layering is one of the major targets in this system. According to the mechanical design, the minimum theoretical depth of the system can reach 2 millimeters. Fix slice depth by the software debugging, and then compared with the data measured by the standard ruler. As shown in Table 2, it can be seen that the relative error was less than 3%, which was good enough for this system.

***Table 2.*** *Comparison between presets and actual measurement value.*

| Items | Preset Value/mm | Measurement Value (AVG)/mm | Error/mm | Relative error |
|---|---|---|---|---|
| Group 1 | 300 | 308 | 8 | 2.67% |
| Group 2 | 700 | 718 | 18 | 2.57% |

Vinegar quality is the most direct evaluation of this system. Two identical fermentation tanks with the same inoculation were used as test samples. The testing group uses Smart Grains-Stirring Machine to stir grains, which is by the automated process; while the control group follows the traditional process. After fermentation is completed, it is necessary to measure vinegar total acid content and non-volatile acid content, and their results are directly related to the performance of this machine. As shown in Table 3, testing group shows better results than control group both on vinegar total acid content and non-volatile acid content. In other words, Smart Grains-Stirring Control System significantly improved the acid production rate.

***Table 3.*** *Comparison between test group and control group.*

| Items | Total Acid Content (AVG)/($10^{-2}$g/mL) | Non-volatile Acid Content (AVG) /($10^{-2}$g/mL) |
|---|---|---|
| Test Group | 7.42 | 2.26 |
| Control Group | 7.11 | 2.13 |

## 4. Conclusion

With the development of industrial automation, China's manufacturing industry is gradually transformed into intelligent manufacturing. Hence, fermentation also requires intelligence and automation. In this project, mechanical design, hardware design, and software design met design requirements, laying a good foundation for the stable operation of the entire system. In this project, the intelligent control system of grains-stirring machines based on an STM32 microcontroller could carry out whole process monitoring of fermentation and automatic adjustment of process parameters, leading to grains-stirring automation. Also, the design could solve some problems in the process of fermentation, and it has great space for development and market competitiveness.

## Acknowledgements

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