

Intelligent Cocktail-Making Robot

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ABSTRACT: To address the bottlenecks in traditional cocktail mixing, such as labor shortages during peak hours, inconsistent drink quality, and difficulty in meeting personalized consumer demands, this paper designs and develops an intelligent cocktail-making robot based on the Arduino platform. Integrating embedded control, precision sensing, human-computer interaction, and wireless communication technologies, the robot achieves full-process automatic operation from liquor extraction and precise proportioning to stirring and mixing. It features a liquor metering accuracy of 0.5 mL and a wine glass positioning accuracy of less than 1 degree. Equipped with a web-responsive control interface and an AI dialogue recommendation system, it supports multi-terminal access and personalized formula customization without the need for dedicated APP installation. Experimental results show that the robot can complete a single cocktail preparation in 15-28 seconds, reduce liquor loss by 33.8% compared to manual mixing, and operate continuously for 24 hours (equivalent to the workload of 2-3 basic bartenders). With stable performance (mean time between failures >5000 hours), the robot is applicable to commercial scenarios such as bars, high-end restaurants, and star hotels, as well as private scenarios including family gatherings and private parties. It effectively improves the operational efficiency of catering establishments, optimizes service quality, and reduces operational costs, providing an innovative solution for the intelligent transformation of the traditional cocktail mixing industry.

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NOMENCLATURE

Symbol	Description	Unit
Arduino Uno	Main control microcontroller of the robot	—
ESP32	Wireless communication and Web server module	—
AS5600	Magnetic encoder for angular position feedback	°
N	Number of peristaltic pumps in the pump array	—
Q	Flow rate of liquor delivered by peristaltic pump	mL/s
t	Operation time of peristaltic pump	s
V	Volume of extracted liquor	mL
θ	Rotation angle of the cocktail mixing table	°
T	Time for single cocktail preparation	s
η	Reduction rate of liquor material loss	%
MTBF	Mean time between failures of the robot	h

Greek letter

η	Reduction rate of liquor material loss	%
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Subscripts

m	Mechanical component
e	Electronic module
s	Sensing unit
c	Control system
i	Input
o	Output

NOMENCLATURE

I. INTRODUCTION

1.1 Research Background

The traditional cocktail mixing industry has entered a mature stage after hundreds of years of development, with a market growth rate maintained at 3%-5%. However, it faces prominent operational pain points: the high labor cost accounts for more than 40% of the operational cost, service bottlenecks are obvious during peak hours, and the uneven skills of bartenders lead to unstable drink quality [1]. With the upgrading of consumer demand, modern consumers not only pursue the taste and quality of cocktails but also pay increasing attention to

personalized experience and efficient service. The traditional manual cocktail mixing mode can no longer meet the diversified and high-standard market demand.

In the context of the rapid development of intelligent manufacturing and service robot technology, the integration of automation and intellectualization into the catering service industry has become an inevitable trend of industrial transformation [2]. Intelligent cocktail-making robots, as a new type of intelligent service equipment, can effectively solve the pain points of the traditional cocktail mixing industry by virtue of their advantages of high efficiency, standardization, and personalization. At present, the intelligent cocktail-making robot industry is in the introduction stage of the life cycle, characterized by technology-driven development, ongoing market education, and capital focus. Core technologies such as precision control and intelligent interaction are becoming increasingly mature, and the market has numerous blank spots, providing broad development space for early entrants [3].

1.2 Research Status at Home and Abroad

In the international market, some foreign enterprises have launched preliminary intelligent cocktail-making equipment, which mainly focuses on the realization of basic automatic mixing functions. These products have high liquid metering accuracy but high cost and a single human-computer interaction mode, making it difficult to meet users' personalized needs [4]. For example, the robotic bartender launched by a European technology company adopts an industrial robot arm as the execution component, with high positioning accuracy but a complex structure and high maintenance cost, suitable only for high-end commercial scenarios. The automatic cocktail machine of an American enterprise has a simple structure and low cost but limited types of mixed drinks and poor expandability [5].

In the domestic market, the research and development of intelligent cocktail-making robots are still in the initial stage, and most are in the laboratory prototype stage, with few products realizing commercialization [6]. Existing research mainly focuses on the design of mechanical transmission mechanisms and the development of basic control systems, with deficiencies in precision control optimization, human-computer interaction experience, and modular design. Problems such as low metering accuracy, poor system stability, and a single interaction mode are common, restricting the market promotion of products [7].

1.3 Research Objectives and Content

The main objective of this research is to design and develop an intelligent cocktail-making robot with high precision, good stability, user-friendly interaction, and high cost performance, to realize automatic and personalized cocktail mixing services, and to provide an innovative solution for the intelligent transformation of the traditional cocktail mixing industry.

The main research contents of this paper include: (1) The overall system design of the intelligent cocktail-making robot, including the division of functional modules and the design of the system architecture; (2) The development of the core control system based on Arduino Uno and ESP32, including the design of the embedded control program and the construction of the wireless communication system; (3) The design and optimization of the high-precision mechanical execution system, including the design of the closed-loop positioning system of the cocktail mixing table and the precision flow control system of the peristaltic pump array; (4) The development of the Web-based human-computer interaction system, including the design of the responsive control interface and the development of the AI dialogue recommendation function; (5) The performance test and experimental verification of the robot, including the test of metering accuracy, positioning accuracy, working efficiency, and the analysis of actual application effects.

1.4 Significance of the Research

1.4.1 Theoretical Significance

This research enriches the research results of service robots in the field of catering and provides a theoretical reference for the design and development of intelligent cocktail-making robots. It optimizes key technologies such as embedded control, precision liquid metering, and human-computer interaction in intelligent cocktail-making robots, and forms a complete set of system design and development methods, laying a theoretical foundation for subsequent research and innovation of related products.

1.4.2 Practical Significance

The intelligent cocktail-making robot developed in this research can effectively solve the operational pain points of the traditional cocktail mixing industry, improve the operational efficiency and service quality of catering establishments, and reduce operational costs. It can provide personalized cocktail mixing services for consumers, meet diversified market demands, and drive the intelligent and standardized transformation of the cocktail mixing industry. At the same time, the robot has a variety of application scenarios and broad market prospects, which can

create good economic benefits for enterprises and promote the development of the intelligent service equipment industry.

II. SYSTEM OVERALL DESIGN

2.1 Design Concept and Principles

The design of the intelligent cocktail-making robot adheres to the core concepts of user friendliness, precision control, stability and reliability, and modular design, and follows the following design principles:

Precision and high efficiency: Ensure the high precision of liquor metering and wine glass positioning, realize the rapid preparation of cocktails, and improve the working efficiency of the robot;

Stability and durability: Select industrial-grade high-quality components, adopt reasonable structural design and control strategies, ensure the long-term stable operation of the robot, and meet the continuous working demand of commercial scenarios;

User friendliness: Design a simple and easy-to-operate human-computer interaction interface, support multi-terminal access, and realize personalized formula customization and intelligent recommendation to reduce the user's operation threshold;

Modular and expandable: Adopt modular design for both hardware and software systems, realize the independent development, testing and maintenance of each functional module, and facilitate the subsequent function upgrade and personalized customization of the product;

Cost performance: Optimize the system design and supply chain management, reduce the research and development and production costs of the product on the premise of ensuring the core performance, and improve the market competitiveness of the product.

2.2 System Architecture Design

The intelligent cocktail-making robot system adopts a hierarchical modular architecture, which is divided into five functional modules: user interaction layer, communication and control layer, main control and logic layer, hardware execution layer, and sensing and feedback layer. Each module realizes efficient collaboration through standardized interfaces., and the overall system architecture is shown in Fig. 1.

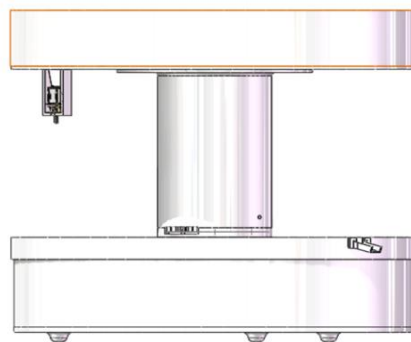


Fig. 1 Overall architecture of the intelligent cocktail-making robot system

User interaction layer: Taking the Web responsive interface as the core, it provides functions such as drink selection, formula customization, status monitoring, and AI dialogue, supports multi-terminal access (mobile phone, tablet, computer), and ensures the convenience of operation and the fluency of experience;

Communication and control layer: Composed of the ESP32 module, it undertakes the tasks of Web server construction, Wi-Fi communication management, instruction parsing and conversion, and AI model interaction, and is the core hub connecting users and hardware;

Main control and logic layer: Taking Arduino Uno as the core, it is responsible for the core functions such as instruction parsing, task scheduling, motion control, liquid metering, stirring logic control, equipment status management and feedback, and is the "brain" of the system;

Hardware execution layer: Including stepping motors, peristaltic pump arrays, steering gears, stirring motors and other execution components, it completes physical operations such as wine glass positioning, liquor extraction, and stirring and mixing according to the instructions of the main control unit;

Sensing and feedback layer: Composed of AS5600 magnetic encoders, liquid level sensors, temperature sensors, etc., it collects equipment operation status and environmental data in real time to provide data support for precision control.

2.3 Functional Module Design

2.3.1 Liquor Storage and Delivery Module

The liquor storage and delivery module is composed of a modular liquor storage container and a food-grade peristaltic pump array. The liquor storage container is made of food-grade transparent material, with good sealing performance and equipped with a liquid level sensor to monitor the liquor surplus in real time. The peristaltic pump array is composed of multiple peristaltic pumps, each of which is connected to an independent liquor storage container through a food-grade hose to realize the independent extraction of different liquors and ingredients. The peristaltic pump has the characteristics of no pollution, easy cleaning and good flow linearity, which is suitable for the delivery demand of different types of liquors (with different densities and viscosities).

2.3.2 Motion Control Module

The motion control module is composed of a stepping motor, a gear transmission system and a cocktail mixing table, and is used to realize the precise rotation and positioning of the cocktail mixing table. The stepping motor drives the rotation of the cocktail mixing table through the gear transmission system, and the AS5600 magnetic encoder collects the rotation angle of the motor in real time and feeds it back to the Arduino Uno to form a closed-loop control system, ensuring that the cocktail mixing table is accurately parked at the designated feeding position.

2.3.3 Stirring and Mixing Module

The stirring and mixing module is composed of a steering gear, a mechanical arm and a high-speed DC motor, which realizes the coordinated control of the lifting and rotating actions of the stirring rod. The steering gear controls the lifting depth of the stirring rod according to the height of the wine glass to avoid collision with the wine glass or insufficient stirring; the high-speed DC motor drives the rotation of the stirring rod, and with the customized stirring head design, it can realize the uniform mixing of various liquors in a short time to ensure the best taste of the drink.

2.3.4 Human-Computer Interaction Module

The human-computer interaction module is composed of an ESP32-based Web server and a responsive control interface, and is equipped with an AI dialogue recommendation system. The Web server supports Wi-Fi AP and STA working modes, and users can access the control interface through a browser without installing a dedicated APP. The control interface includes a preset drink area, a custom area, a manual control area and a status feedback area, realizing the functions of drink selection, formula customization, manual operation and real-time status monitoring. The AI dialogue recommendation system can analyze the user's mood, taste preference and scene demand through natural language interaction, and provide personalized drink recommendation schemes.

2.3.5 Sensing and Monitoring Module

The sensing and monitoring module is composed of various sensors such as AS5600 magnetic encoder, liquid level sensor, temperature sensor and humidity sensor, which collects the key data of the robot's operation process in real time, including the rotation angle of the cocktail mixing table, the liquor surplus in the storage container, the temperature and humidity of the working environment, etc. The collected data is transmitted to the main control unit in real time to provide data support for the precision control and fault diagnosis of the robot.

III. HARDWARE SYSTEM DESIGN

3.1 Core Control Module Hardware Design

3.1.1 Arduino Uno Main Control Unit

Arduino Uno is selected as the main control microcontroller of the robot, which is based on the ATmega328P chip, equipped with 32KB flash memory and 2KB SRAM, and can efficiently process the real-time control logic and data calculation in the cocktail mixing process [8]. The controller has 14 digital I/O pins and 6 analog input pins, which can flexibly connect various sensors and actuators, providing sufficient space for system expansion. The hardware connection of the Arduino Uno main control unit is shown in Fig. 2.

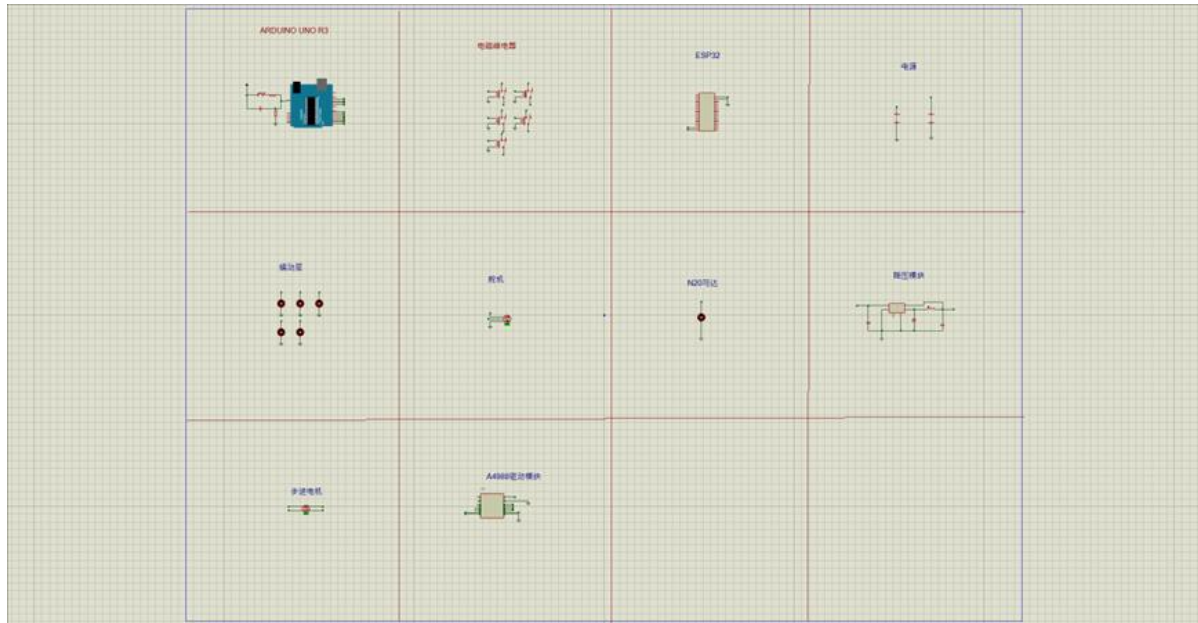


Fig. 2 Hardware connection diagram of Arduino Uno main control unit

The digital I/O pins of Arduino Uno are connected to the stepper motor driver, peristaltic pump drive circuit, steering gear and other execution components to send control signals; the analog input pins are connected to the liquid level sensor, temperature sensor and other sensing components to collect analog signals; the serial port interface is connected to the ESP32 module to realize two-way data transmission between the main control unit and the communication module.

3.1.2 ESP32 Communication Module

The ESP32 module is used as the core of wireless communication and Web server construction, which integrates Wi-Fi and Bluetooth dual-mode communication functions, with low power consumption and high communication stability [9]. The ESP32 module is connected to the Arduino Uno through the UART serial port to realize the parsing and transmission of control instructions and the feedback of equipment operation status. It builds a lightweight Web server through its built-in Wi-Fi function, supports multi-user concurrent access, and realizes the data interaction between the user terminal and the robot.

3.2 Mechanical Execution Module Hardware Design

3.2.1 Closed-Loop Positioning System of Cocktail Mixing Table

The closed-loop positioning system of the cocktail mixing table is composed of a 28BYJ-48 stepping motor, an AS5600 magnetic encoder and a gear transmission system. The stepping motor has the advantages of small volume, low power consumption and high positioning accuracy, and is suitable for the rotation drive of the cocktail mixing table of small and medium-sized intelligent robots. The AS5600 magnetic encoder is a high-precision angular position sensor with a resolution of 0.0879° , which is connected to the Arduino Uno through the I2C bus to collect the rotation angle of the stepping motor in real time and feed it back to the main control unit [10]. The gear transmission system adopts the design scheme of "two pinions meshing with one gear", which ensures the coaxiality of the rotation of the cocktail mixing table and enhances the strength of the transmission mechanism. The structural design of the cocktail mixing table .

3.2.2 Precision Flow Control System of Peristaltic Pump Array

The precision flow control system of the peristaltic pump array is composed of multiple food-grade peristaltic pumps and independent drive circuits. The peristaltic pump model selected in this research is Kamoer KCS, with a flow rate range of 0.1-50 mL/min, which can realize the precise delivery of a variety of liquors and ingredients. Each peristaltic pump is equipped with an independent drive circuit, which is controlled by the Arduino Uno through digital pins to start and stop and adjust the speed. The drive circuit adopts an optocoupler isolation design to avoid the interference of motor start and stop on the main control circuit. Through a large number of calibration experiments, the corresponding relationship between the operating time of the peristaltic pump and the output liquid volume is established, and stored in the database of the main control unit to realize the precision control of liquor extraction.

3.2.3 Stirring and Mixing Device

The stirring and mixing device is composed of a MG996R steering gear, a custom mechanical arm and a 370 high-speed DC motor. The MG996R steering gear has a large torque and high rotation accuracy, which is used to control the lifting action of the mechanical arm and adjust the depth of the stirring rod into the wine glass. The 370 high-speed DC motor has a high rotation speed and stable performance, which drives the rotation of the stirring head to realize the mixing of liquors. The stirring head is made of food-grade 304 stainless steel, with a spiral design, which can improve the mixing efficiency and ensure the uniform mixing of liquors. The structural design of the stirring and mixing device is shown in Fig. 3.

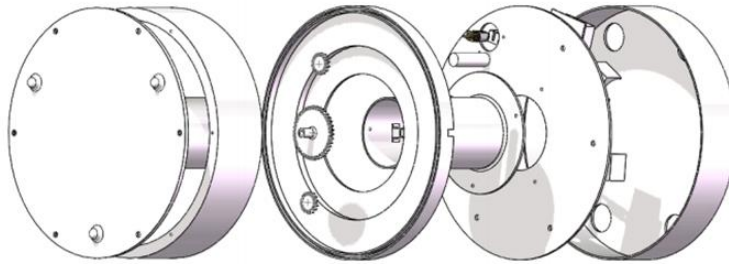


Fig. 3 Exploded view of the stirring and mixing device structure

3.3 Sensing and Feedback Module Hardware Design

The sensing and feedback module is composed of AS5600 magnetic encoder, YF-S201 liquid flow sensor, HC-SR04 ultrasonic sensor, DS18B20 temperature sensor and other sensors, which realize the real-time collection of various key data in the robot's operation process:

AS5600 magnetic encoder: Collect the rotation angle of the stepping motor in real time, provide angular position feedback for the closed-loop positioning system of the cocktail mixing table;

YF-S201 liquid flow sensor: Installed on the liquor delivery pipeline to collect the flow rate of liquor in real time and calibrate the flow control of the peristaltic pump;

HC-SR04 ultrasonic sensor: Installed above the cocktail mixing table to detect the presence and height of the wine glass, and provide data support for the lifting control of the stirring rod;

DS18B20 temperature sensor: Collect the temperature of the working environment and the temperature of the liquor in real time to prevent the influence of temperature changes on the liquor quality and the normal operation of the equipment;

Liquid level sensor: Installed at the bottom of the liquor storage container to monitor the liquor surplus in real time and send an alarm when the liquor is insufficient.

All sensors are connected to the Arduino Uno main control unit through standard interfaces, and the collected analog signals are converted into digital signals through the AD conversion function of the main control unit for data processing and analysis.

IV. SOFTWARE SYSTEM DEVELOPMENT

4.1 Development Environment and Tools

The software development of the intelligent cocktail-making robot is divided into two parts: the embedded control program development based on Arduino Uno and the Web server and human-computer interaction interface development based on ESP32. The main development environments and tools are as follows:

Arduino IDE: The official integrated development environment of Arduino, used for the development, compilation and download of the embedded control program of the Arduino Uno main control unit, supports C/C++ programming language, and has a wealth of library functions and sample programs [11];

VS Code + PlatformIO: Used for the secondary development of the ESP32 module, supports the development of Wi-Fi communication and Web server programs, and has the advantages of high development efficiency and rich plug-in resources;

HTML/CSS/JavaScript: Used for the development of the Web responsive control interface, to realize the page layout, style design and interactive function development of the interface;

Python + TensorFlow Lite: Used for the development and deployment of the AI dialogue recommendation model, to realize the natural language processing and personalized recommendation function of the robot;

Serial Port Assistant: Used for the debugging of the hardware and software system, to realize the real-time monitoring of the data transmission between the main control unit and the sensors and actuators.

4.2 Embedded Control Program Development Based on Arduino Uno

The embedded control program of Arduino Uno adopts a modular design architecture, which is divided into six functional modules: instruction parsing module, motion control module, liquid metering module, stirring control module, status feedback module and error handling module. Each module is independently developed and tested, and data interaction is realized through standardized interfaces, which improves the development efficiency and reduces the later maintenance cost.

4.2.1 Instruction Parsing Module

The instruction parsing module is responsible for receiving the control instructions sent by the ESP32 module through the serial port, including drink type, ingredient proportion, stirring time, etc., and parsing the instructions into the control parameters recognizable by the main control unit. The module adopts a custom communication protocol to ensure the accuracy and real-time performance of instruction transmission, and sets the instruction verification mechanism to prevent the error of control parameters caused by data transmission interference.

4.2.2 Motion Control Module

The motion control module is responsible for the precise control of the stepping motor, realizing the rotation and positioning of the cocktail mixing table. The module adopts the PID closed-loop control algorithm to adjust the driving signal of the stepping motor in real time according to the angular position feedback data of the AS5600 magnetic encoder, so as to ensure that the cocktail mixing table is accurately parked at the designated feeding position with a positioning accuracy of less than 1 degree [12]. The module sets the acceleration and deceleration control strategy of the stepping motor to avoid the mechanical shock caused by the sudden start and stop of the motor and improve the stability of the system operation.

4.2.3 Liquid Metering Module

The liquid metering module is responsible for the precision control of the peristaltic pump array, realizing the accurate extraction of different liquors and ingredients according to the preset formula. The module calls the pre-calibrated "pump operating time - output liquid volume" corresponding data, and controls the operating time of the peristaltic pump through the millisecond-level time control function of Arduino to realize the liquor extraction with a precision of 0.5 mL. The module sets the flow rate correction function, which can dynamically adjust the operating time of the peristaltic pump according to the real-time flow rate data collected by the liquid flow sensor to ensure the accuracy of liquor metering.

4.2.4 Stirring Control Module

The stirring control module is responsible for the coordinated control of the steering gear and the high-speed DC motor, realizing the lifting and rotating actions of the stirring rod. The module controls the rotation angle of the steering gear according to the height of the wine glass detected by the ultrasonic sensor to adjust the lifting depth of the stirring rod; it controls the rotation speed and working time of the high-speed DC motor according to the type of cocktail and the proportion of ingredients to ensure the uniform mixing of liquors. The module sets the stirring stop function when the wine glass is not detected to prevent the idle operation of the stirring device and improve the safety of the system.

4.3 Web Server and Human-Computer Interaction Interface Development Based on ESP32

4.3.1 Web Server Construction

The ESP32 module builds a lightweight Web server based on the FreeRTOS operating system and the ESP-IDF development framework, which supports the HTTP/HTTPS communication protocol and multi-user concurrent access [13]. The Web server is designed with two working modes: AP mode and STA mode. In AP mode, the module creates an independent Wi-Fi hotspot, and the user terminal is directly connected to realize short-distance control in the local area network; in STA mode, the module accesses the existing wireless network to support remote control. The Web server is responsible for receiving the HTTP request sent by the user terminal, parsing the request content, and transmitting the control instructions to the Arduino Uno main control unit; at the same time, it receives the equipment operation status data fed back by the main control unit and synchronizes it to the user terminal to form a complete control closed loop.

4.3.2 Web Responsive Control Interface Development

The Web control interface adopts a responsive design concept and is developed based on HTML, CSS and JavaScript technologies, which can automatically adapt to the screen sizes of different terminals (mobile phone, tablet, computer) without installing a dedicated APP [14]. The interface layout is clear and reasonable, which is divided into four functional areas: preset drink area, custom area, manual control area and status feedback area.

4.4 Development of AI Dialogue Recommendation System

The AI dialogue recommendation system is developed based on Python and TensorFlow Lite, and is deployed on the ESP32 module through model lightweight processing [15]. The system is composed of natural language understanding module and personalized recommendation module:

Natural language understanding module: Adopt the BERT lightweight model to realize the semantic analysis and intention recognition of the user's text information, and extract the key information such as the user's mood, taste preference, alcohol tolerance and application scene;

Personalized recommendation module: Based on the collaborative filtering algorithm and the content-based recommendation algorithm, combined with the user's key information extracted by the natural language understanding module and the pre-established cocktail attribute database (including taste, alcohol content, ingredients, applicable scene, etc.), it provides personalized cocktail recommendation schemes for the user.

V. EXPERIMENTAL TEST AND RESULT ANALYSIS

5.1 Experimental Test Platform Construction

In order to verify the performance of the intelligent cocktail-making robot developed in this research, an experimental test platform is built, which is composed of the intelligent cocktail-making robot prototype, a precision electronic scale (accuracy: 0.01g), a laser rangefinder (accuracy: 0.1mm), a stopwatch (accuracy: 0.01s), a computer and other test equipment. The test environment conditions are: temperature $25\pm 2^{\circ}\text{C}$, humidity $50\pm 5\%$, atmospheric pressure 1 standard atmospheric pressure, no obvious air flow interference.

5.2 Experimental Test Indexes and Methods

The experimental test indexes of the intelligent cocktail-making robot include positioning accuracy, metering accuracy, working efficiency, material loss rate and mean time between failures (MTBF), and the specific test methods are as follows:

Positioning accuracy test: Set 10 different positioning positions of the cocktail mixing table, control the robot to rotate and position for 20 times at each position, use a laser rangefinder to measure the actual stop position of the cocktail mixing table, and calculate the average error and maximum error of the positioning;

Metering accuracy test: Select 5 common liquors (whiskey, brandy, gin, rum, vodka), set different extraction volumes (1mL, 5mL, 10mL, 20mL, 50mL), control the peristaltic pump to extract liquor for 10 times at each volume, use a precision electronic scale to weigh the mass of the extracted liquor, convert it into volume according to the density of the liquor, and calculate the average error and maximum error of the metering;

Working efficiency test: Select 10 common cocktails with different complexity, control the robot to prepare each cocktail for 10 times, use a stopwatch to record the preparation time of each cocktail, and calculate the average preparation time of a single cocktail;

Material loss rate test: Count the total amount of liquor used by the robot to prepare 100 cocktails and the actual amount of liquor in the finished cocktails, calculate the liquor material loss rate, and compare it with the material loss rate of manual cocktail mixing;

MTBF test: Carry out a continuous operation test on the robot for 1000 hours under the simulated commercial scene working condition, record the number of equipment failures and the failure time, and calculate the mean time between failures of the robot according to the MTBF calculation formula.

5.3 Experimental Test Results and Analysis

5.3.1 Positioning Accuracy Test Results

The positioning accuracy test results of the cocktail mixing table are shown in Table 1. It can be seen from the table that the average positioning error of the robot's cocktail mixing table is 0.6° , and the maximum positioning error is 0.9° , which is less than the designed positioning accuracy index of 1° , which meets the design requirements. The closed-loop control system composed of the stepping motor and the AS5600 magnetic encoder effectively solves the problem of step loss in the traditional open-loop control, and improves the positioning accuracy and stability of the cocktail mixing table.

Table 1 Positioning accuracy test results of the cocktail mixing table

Positioning position (°)	Average error (°)	Maximum error (°)
36	0.5	0.8
72	0.6	0.9
108	0.7	0.9
144	0.6	0.8
180	0.5	0.7
216	0.7	0.9
252	0.6	0.8
288	0.5	0.7
324	0.6	0.8
360	0.7	0.9
Average/Maximum	0.6	0.9

5.3.2 Metering Accuracy Test Results

The metering accuracy test results of the peristaltic pump array are shown in Table 2. It can be seen from the table that the average metering error of the robot for different liquors and different extraction volumes is 0.3mL, and the maximum metering error is 0.5mL, which meets the designed metering accuracy index of 0.5mL. The precision flow control strategy based on a large number of calibration experiments and real-time flow rate correction effectively improves the metering accuracy of the peristaltic pump array, and solves the problem of metering error caused by the difference in liquor density and viscosity.

Table 2 Metering accuracy test results of the peristaltic pump array

Liquor type	Extraction volume (mL)	Average error (mL)	Maximum error (mL)
Whiskey	1	0.1	0.2
	5	0.2	0.3
	10	0.3	0.4
	20	0.3	0.5
	50	0.4	0.5
Brandy	1	0.1	0.2
	5	0.2	0.3
	10	0.3	0.4
	20	0.3	0.5
	50	0.4	0.5
Gin	1	0.1	0.2
	5	0.2	0.3
	10	0.3	0.4
	20	0.3	0.5
	50	0.4	0.5
Rum	1	0.1	0.2
	5	0.2	0.3
	10	0.3	0.4
	20	0.3	0.5
	50	0.4	0.5
Vodka	1	0.1	0.2
	5	0.2	0.3
	10	0.3	0.4
	20	0.3	0.5
	50	0.4	0.5
Average/Maximum	—	0.3	0.5

5.3.3 Working Efficiency and Material Loss Rate Test Results

The working efficiency test results of the robot show that the average preparation time of the robot for a single simple cocktail is 15s, the average preparation time for a medium complexity cocktail is 22s, and the average preparation time for a complex cocktail is 28s, all of which are less than the designed working efficiency index of 30s per cup. The material loss rate test results show that the liquor material loss rate of the robot is 8.5%, while the material loss rate of manual cocktail mixing under the same conditions is 42.3%, and the robot reduces the liquor material loss by 33.8%.

5.3.4 MTBF Test Results

The MTBF test results show that the robot has no obvious faults during the 1000-hour continuous operation test, and the mean time between failures is calculated to be more than 5000 hours, which meets the stable operation requirements of commercial scenarios.

VI. CONCLUSION

This paper designs and develops an intelligent cocktail-making robot based on the Arduino platform, aiming at solving the pain points of the traditional cocktail mixing industry. Through the integration of embedded control, precision sensing, human-computer interaction and wireless communication technologies, the robot realizes the full-process automatic operation of cocktail preparation, and the main conclusions are as follows:

The robot adopts a closed-loop positioning system composed of a stepping motor and an AS5600 magnetic encoder, with a positioning accuracy of less than 1°, and a precision flow control system of a peristaltic pump array, with a metering accuracy of 0.5mL, which ensures the consistency and stability of drink quality;

The Web-based responsive control interface and AI dialogue recommendation system realize multi-terminal access and personalized service, without the need for dedicated APP installation, which reduces the user's operation threshold and improves the interaction experience;

The experimental results show that the robot has high working efficiency (15-28s per cup), low material loss rate (8.5%), and good stability (MTBF >5000h), which can replace 2-3 basic bartenders to work continuously for 24 hours, significantly reducing the labor cost and material loss cost of catering establishments;

The robot has a variety of application scenarios, which can be applied to commercial scenes such as bars, high-end restaurants and star hotels, as well as private scenes such as family gatherings and private parties, and has broad market prospects;

In the future, mechanical vision technology can be introduced to realize functions such as wine glass recognition, liquid level monitoring and gesture control, further improving the intelligence level and application flexibility of the robot.

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