Intelligent Ball-Picking Robot Based on Ducted Fan Power

Xufeng Huang, Bingxuan Jiang, Dongda Cai*, Qingjian Lin, Yiming Fang , Kainan Xiao, Lei Pei

NingboTech University, Ningbo, 315100, China
**Corresponding author: cynthiac@nbt.edu.cn*

Abstract: *This robot uses STM32F103RCT6 as the control core and relies on ducted fan power as the primary ball-picking mechanism. The ball is collected using the inertia of the ball as the robot moves forward and the suction from the ducted fan, allowing the ball to enter the collection box above the robot. The robot completes the ball-picking process when it moves across all positions within the field and picks up all the balls in its path. It offers two control modes: manual and fully automatic. The robot integrates multiple functions, including remote control, Bluetooth, tracking, distance sensing and obstacle avoidance, ducted fan power, solar energy, and visual recognition.*

Keywords: *Ducted Fan Power; Manual Control; Fully Automatic; Distance Sensing and Obstacle Avoidance; Solar Energy; Visual Recognition*

Introduction

With the national policies promoting nationwide fitness and sports consumption, the vitality of the sports market and the enthusiasm for sports consumption have been further stimulated. More and more people are engaging in sports, leading to increased demand for sports venues and equipment. The construction of sports facilities such as table tennis halls, badminton courts, and tennis courts is on the rise, and the audience for ball sports is growing. This development has led to higher expectations for the sports experience and ball-picking efficiency.

The intelligent ball-picking robot, with the ducted fan as the core component, moves using two front wheels and a caster wheel. When encountering a small ball, the ducted fan is activated, creating a negative pressure in the collection box. The robot uses ultrasonic radar for autonomous movement and the ducted fan for ball pickup. The ball is pulled into the collection box above the robot using the ball's inertia as the robot moves and the suction from the ducted fan. After the ball is picked up, the robot can shoot the ball out again, acting as a practice partner. The robot supports both manual and fully automatic control modes and integrates remote control, Bluetooth, tracking, distance sensing and obstacle avoidance, ducted fan power, solar energy, and visual recognition. It has notable advantages, such as a simple structure, flexible movement, low cost, and high ball-picking efficiency.

1. Research Status at Home and Abroad

Currently, some scholars in China have proposed devices that use fan suction for ball picking, while others have designed mechanical systems that use vacuum pumps for ball collection. However, both methods face issues such as high noise levels and the intake of dust. In a paper by Liu Xiujie and colleagues, although these problems were avoided, the system relies on elastic ropes with intervals to collect balls using elastic force, which reduces the ball-picking efficiency. Similarly, scholars like Zhou Xu proposed using robotic arms for ball picking, but this method faces the same issue, with the up-and-down motion of the robotic arm leading to reduced picking efficiency[1].

There has been limited research on robots for picking small spherical objects, with most robots being designed for picking up golf balls, tennis balls, table tennis balls, and shuttlecocks. Based on the working principle, these robots can be classified into different types, such as robotic arm-type, combined-type, sweeping-type, air-suction-type, roller-type, drum-type, and spring-type ball-picking robots.

2. Design Plan

2.1 Plan Concept

2.1.1Design an Intelligent Ball-Picking Robot

The goal is to design a highly intelligent ball-picking robot capable of tracking, obstacle avoidance, and automatic ball collection.

2.1.2 Vehicle Model Design

The robot adopts a vehicle model, allowing it to pick up balls while minimizing the potential for obstructing traffic, ensuring smooth movement and operational efficiency.

2.1.3 Extended Work Time through Timed Operation and Battery Capacity Expansion

By incorporating timed operation, the robot will work continuously for extended periods. The battery capacity is increased to ensure long-term operational efficiency, ensuring the robot can work for longer durations and cover larger areas for ball collection.

2.1.4 Tracking Principle

The robot is equipped with a tracking module and line-following sensors on its body. These sensors detect the reflection of light from the ground, enabling the robot to follow a predefined path automatically.

2.1.5 Visual Recognition for Intelligent Ball Detection

The robot will incorporate visual recognition technology, allowing it to autonomously identify balls and collect them. This enables intelligent ball picking without manual intervention[2-4].

2.1.6 Solar Power for Sustainable Operation

A solar energy module is integrated into the robot, ensuring the system can operate autonomously for extended periods while minimizing energy consumption. The solar module maximizes the robot’s ability to run efficiently while reducing reliance on external power sources.

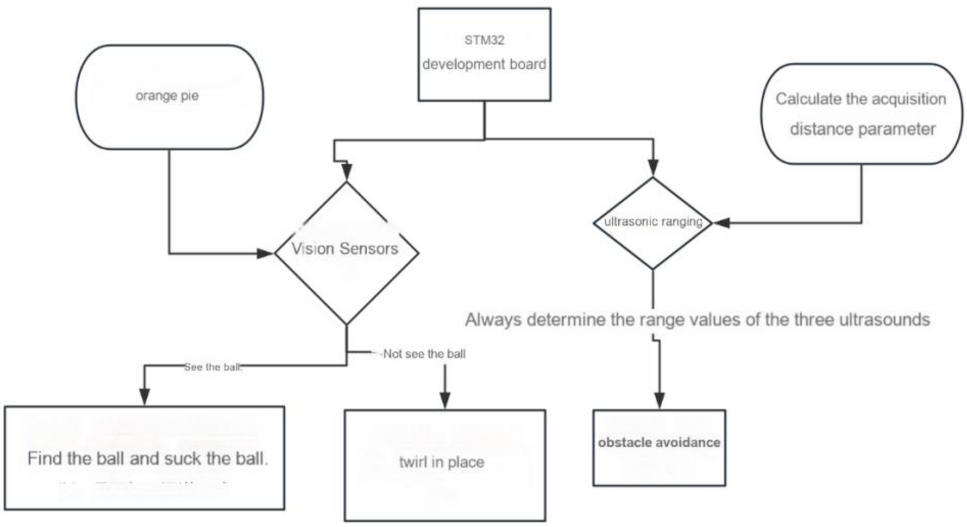
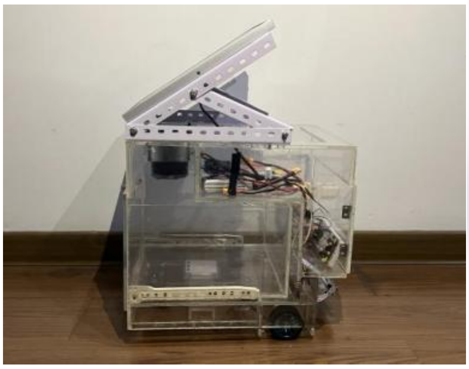


Fig. 1 Flowchart

2.2 Mechanical Components

The front of the robot is equipped with a rotating wheel, which can be used to pick up objects along its path. The center of the robot's body houses a drawer-style collection box, which is fully enclosed to ensure the stability of the collection box during movement. The enclosed design effectively prevents objects from spilling out due to bumps or uneven terrain. The drawer-style collection box can be easily pulled out and reinserted, providing significant convenience for subsequent collection and organization of items. The inner box and outer shell are connected by a press-fit buckle structure, which not only ensures a stable connection but also guarantees ease of operation[5-7].



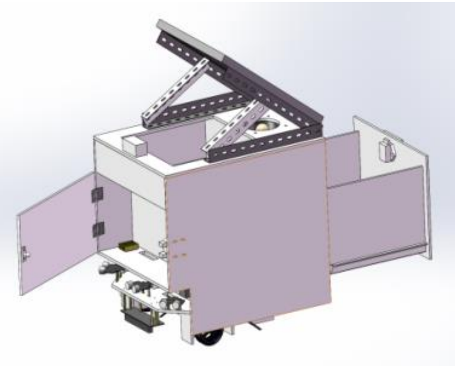


Fig. 2 SW conceptual diagram

Fig. 3 Physical map

2.3 Remote Control Design

2.3.1 Brushless Electronic Speed Controller for RC Models

Standard remote-controlled models (RC models) follow a defined signal format for remote control. The transmitter sends a signal with a period of 20 ms, which includes multiple channels. Each channel is controlled by a pulse with a width of 1 ms to 2 ms, which is used to regulate the motor speed or other functions of the vehicle[8]. The Pulse Width Modulation (PWM) control method works by controlling the on/off state of the switching devices in the inverter circuit, producing a series of equal amplitude pulses. These pulses replace the sine wave or required waveform, and by modulating the pulse width in a specific pattern, the output voltage and frequency of the inverter circuit can be controlled.

3. Working Principle and Performance Analysis

The structure of the intelligent ball-picking robot includes two front wheels and a caster wheel, allowing it to move and turn flexibly in complex environments. The control system is based on the STM32 microcontroller, which manages the robot's movement and ball-picking operation.

The ultrasonic radar acts as the robot's perception module, allowing it to measure the distance to obstacles in real time[9]. This enables the robot to adjust its path to avoid obstacles. The ultrasonic sensor used is the HC-SR04 module, which has a distance measurement accuracy of 3 mm. The measurement principle is based on the fact that ultrasonic waves travel to an obstacle and back, with the time taken for the waves to travel providing the distance information.

$$S = \frac{t \times v}{2} \quad (1)$$

Where:

S is the distance measured by the ultrasonic sensor,

t is the actual time taken for the ultrasonic wave to travel to the obstacle and return,

v is the speed of sound in the air (340 m/s).

Obstacle Avoidance and Movement Control: Two distance measurement modules are installed at the front of the robot, positioned at the center and on the left and right sides. These sensors are used to obtain the distance to obstacles in the robot's path via the microcontroller. The robot uses these distance readings to decide whether it needs to adjust its path. If the distance to an obstacle reaches a predefined threshold, the robot will control the motors to adjust its movement and avoid collisions.

If an obstacle is detected in front of the robot, it will first reverse, then turn right by a certain distance. Similarly, if an obstacle is detected on the left side, the robot will reverse and then turn right by a certain distance. If the obstacle is on the right side, the robot will turn left to avoid it. Due to fluctuations in the distance measurement data, data filtering is applied to ensure that sudden changes in the sensor readings do not interfere with the robot's normal movement.

4. Testing

4.1 Manual and Robotic Ball Pickup Test

In practical tests, the time taken for manual human ball pickup was compared to the robotic ball pickup time. The results showed that there was a significant difference between the time required for human and robotic ball pickup. The robot demonstrated a more efficient ball collection process, highlighting the time-saving advantages of automation in repetitive tasks.

serial numberl	starting momentr,(s)	closing momentt,(s)	pickup timer,(s)
1	0	1.1	1.1
2	4.3	5.4	1.1
3	6.5	7.6	1.1
4	9.6	11.1	1.5
6	13.1	14.8	1.7
7	15.8	17.2	1.4
8	20.2	21.6	1.4
9	23.6	25.1	1.5
10	31.7	32.7	1.0

Fig. 4 Human Pickup Time test data

serial number	starting momentr,(s)	closing momentr(s)	pickup time1,(s)
1	0	2.1	2.1
2	2.1	3.9	1.8
3	3.9	5.3	1.4
4	5.3	6.7	1.4
6	6.7	8.5	1.8
7	8.5	10.4	1.9
8	10.4	12.4	2.0
9	12.4	14.2	1.8
10	14.2	16.5	2.3

Fig. 5 Machine pickup time time test data

The data comparison, represented in the line graph, clearly shows that the robotic ball-picking speed is significantly faster than the human manual ball-picking speed. This proves the superiority and advancement of using a robotic system for ball collection. In the graph, the line at the top represents the time taken by humans to pick up the ball, while the lower line shows the time taken by the robot to perform the same task.

This comparison visually demonstrates the efficiency of automation, especially in tasks that involve repetitive actions, such as picking up balls in sports environments. The robot's ability to complete the task more quickly and consistently further highlights its potential for application in various practical scenarios where time and precision are essential.

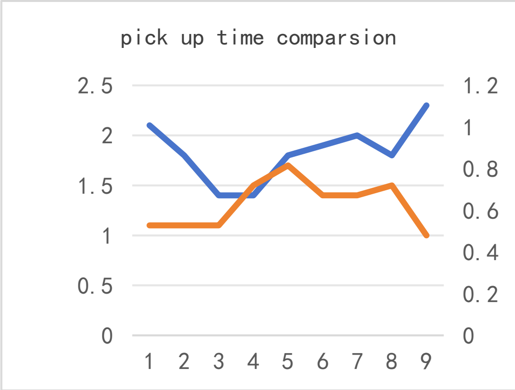


Fig. 6 Line graph comparing pickup time

4.2 Visual Recognition Accuracy Test

Ping pong balls are typically orange or white, so color is one of the key features of the ball. However, due to significant differences in lighting between indoor and outdoor environments, the color can vary greatly. Therefore, it is necessary to conduct measurements in real scenarios. An RGB color statistical model is used to perform a statistical analysis of the ping pong ball's color in actual environments.

Based on the statistical histogram analysis, the histogram range for the R, G, and B channels in each sample can be obtained. To ensure that all ping pong balls are recognized, the maximum range is selected as the binarization threshold.

Table 1 Histogram range for each RGB color statistic

	Sample 1	Sample 2	Sample 3	Sample 4	Experimental selection range
RED（R）	175-250	165-255	150-255	180-245	150-255
GREEN（G）	210-260	200-255	205-250	200-260	200-260
BLUE（B）	20-210	21-200	0-220	51-190	0-220

After multiple tests and training, the average accuracy of ping pong ball recognition reached 87.26%. To account for the occasional color variations of the balls, the team also conducted visual training for tennis balls.

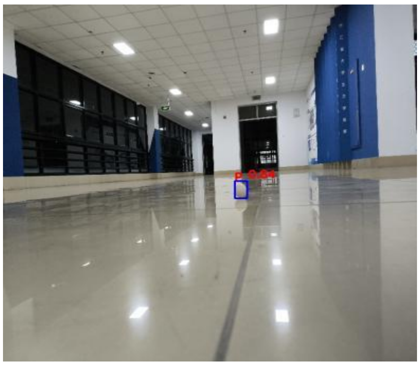


Fig. 7 Single sphere recognition

Table 2 Accuracy for different spheres

form	detection target	Average stacking
01	White ping pong balls	87.6%
02	Orange Table Tennis Balls	92.3%
03	green tennis	82.3%

Conclusion

Through technological innovation and focusing on user needs, the robot has achieved automated ball recognition, collection, and shooting functions, reducing labor costs and improving ball collection efficiency. Its remote control and monitoring capabilities also break through the limitations of traditional ball collection equipment, allowing users to operate and manage the robot anytime and anywhere. Compared to competing products, the robot has clear advantages. With the continuous growth of market demand, it is believed that the robot will achieve sustained success in the market and bring more innovation and development to the sports equipment industry.

References

[1] Li Liqin. Research on the Supply Status and Development Countermeasures of Public Sports Service Products in Large Sports Venues in Henan Province[D]. Henan University, 2021.

[2] Liu Xiu-jie, Zhu Chang-sheng, Wang An-hang, et al. Design and Realization of a Ping Pong Ball Collecting Robot[J]. Mechanical Design and Manufacturing, 2022, 380(10):251-256,261.

[3] Xu Dong-wei, Liu Jian-qun, Lin Gan. Design and Realization of a Ping Pong Ball Collecting Robot[J]. Machine Tools and Hydraulics, 2014(3):16-19,50.

[4] Liu Shi-wen. Mechanical Structure Design of an Automatic Ping Pong Ball Collecting Robot[J]. Science and Technology Innovation and Application, 2019,(9).

[5] Liu Xiu-jie, Zhu Chang-sheng, Wang An-hang, et al. Design and Realization of a Ping Pong Ball Collecting Robot[J]. Mechanical Design and Manufacturing, 2022, 380(10):251-256,261.

[6] Zhou Xu, Zhou Hai-bo, Chen Rui, et al. Design of a Ball Collecting Robot Based on Binocular Vision[J]. Machine Tools and Hydraulics, 2020, 48(3):34-40,79.

[7] Yan Yan-hong. Design of a Simple Ultrasonic Blind Assistance System Based on a Microcontroller[J]. Science and Technology Innovation, 2024,(23):39-41.

[8] Chen Zhuang-zhuang, Yang Yu-lin. A Comparative Study of Deceptive and Suppression Interference in PWM Modulated Model Aircraft Remote Control Systems[J]. Science and Technology Innovation, 2017,(34):63-65.

[9] Qin Ya-lang, Shang Ming-li. Research on a New Type of Passenger Door Anti-Pinch System Based on Ultrasonic Radar Automatic Detection Technology[J]. Special Purpose Vehicles, 2024,(08):63-66.