Mechanical Design of Service Robot for Shuttlecock Sports

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Abstract. Shuttlecock ball is a popular sport in modern society which including entertainment, skills, mass, fitness, popularity and education. The current status artificial ball picking during the training and sports of the shuttlecock sports was reviewed in this paper. Based on the main structure and working principle of the picking robot, it was designed and presented here. It is designed by the three-dimensional CAD software. Through motion simulation analysis, the actual working process of the shuttlecock collection robot was shown. The structure design and motion simulation analysis of the whole machine were carried out and it verified the feasibility of the design. The shuttlecock collection robot is used of retrieving, sorting and placing the shuttlecock. It could effectively solve the inconvenience cause by the manual collecting in shuttlecock ball sports.

Keywords: shuttlecock sports; sport service robot; shuttlecock collection; collection robot; mechanical design.

1. Introduction
Shuttlecock ball sport is becoming more and more popular because of its strong entertainment and not critical restricted by weather and field conditions. The shuttlecock begins to move towards the world in the exchange activities. It has developed in many countries of Europe, Asia and the United States, where the players have established the international sports organizations with the world championship system. At present, player has to pick up balls by hands in games or training. It not only costs a lot of manpower, but also delays sports time. Sports service robot is the typical service automation [1, 2]. The one designed for the sports could play an important role in promoting the scientific training and level improvement of sports players [3]. Some researchers have focused on the theoretical research on the application of the shuttlecock dynamics [4, 5]. There are some prototypes for the badminton sports, which could be referred for the shuttlecock [6, 7]. It is necessary to design a robot with the function of collecting shuttlecock automatically. This paper studies the working principle of the shuttlecock collector. The design of the shuttlecock collector and service robot is carried out by using CAD software and presented here. It has the advantages of fast collection speed and high working efficiency.

2. Working plan and principles
The shuttlecock collector robot is designed to collect the shuttlecock balls during the sports. It is a typical sports service auto machine. Before the mechanical overall design, the work plan with principles should be worked out. The work plan with operation flow is shown in Figure 1. As shown in Figure 1, it firstly collects the shuttlecock balls and transfers them into the machine inner through the collection
part. Then it adjusts the shuttlecock balls’ positions through the transfer part. After that the carding and inspections part checks and combs the balls. Finally, it pushes the good shuttlecock balls into the storage device by the push rod part.

3. Mechanical overall design

The shuttlecock collection robot is designed with composition of the collection part, the transfer part, the carding and inspection part, the push rod part and the storage part. The overall structure is a wireframe shown in Figure 2. In the Figure 2, Label 1 is the storage part, which is used to store the shuttlecock balls. Label 2 is designed as the push rod part. It can push the shuttlecock to the box. Label 3 is the collection part, which could collect the shuttlecock to the inside. The transfer part labelled 4 is used to move the shuttlecock ball and adjust the positions. The carding and inspection part is labelled 5 and used to check and comb the shuttlecock ball.

![Figure 1](image1.png)

**Figure 1.** Work plan with operation flow.

![Figure 2](image2.png)

**Figure 2.** Overall structure of robot (the right is the symmetric view with the left).

4. Mechanical parts design

4.1. Collection part.

The collection part is mainly composed of fans and rotating collection blades. The rotating blades are rotated by the connected rollers. It can rotate the shuttlecock balls and push them into the internal of the robot. The collection part model is designed as shown in Figure 3.
4.2. Transfer part.
The transfer part with one manipulator model is shown in Figure 4. It is composed of the groove wheel mechanism and the connecting rod mechanism. As shown in Figure 4, the hydraulic pole is labelled 1 and used to provide power for telescopic movement of manipulator. Label 2 is the screw thread and it makes the nut move in a straight line. Label 3 is the nut, which is designed to drive the connecting rod movement. The connecting rod is labelled 4 and could move the clamping arm. Label 5 is the clamp arm and used to clip and hold the shuttlecock ball.

During the operation, the motor drives the slot wheel for the rotation. It makes the manipulator rotate intermittently to change the shuttlecock position. The manipulator is composed of hydraulic rod, screw thread rod, nut, connecting rod and clamping arm. The hydraulic rod and screw thread rod are connected in proper positions of the manipulator. The hydraulic cylinder drives the manipulator for the linear reciprocating motion. The screw thread rod, nut, the connecting rod and the clip arm are connected in turn. Motor drives the thread rod to arrange shuttlecock balls in a straight line. With helps of the loosening and clamping arm, the accurate positioning of shuttlecock balls is obtained.

4.3. Carding part.
The carding part is mainly composed of worm, gear and brush. The turbine worm assembly is connected with the motor and disc. The lower end of the disc is equipped with an infrared induction device to determine the position. The motor drives the worm gear component movement with the brush. It combs shuttlecock balls’ feathers. The carding device is shown in Figure 5.

4.4. Push rod part.
The push rod device is mainly composed of crank rocker mechanism and push rod. The motor drives the original rod rotation. The original rod drives the connecting rod to make the push rod linear reciprocate move. It could push the shuttlecock into the collection box. The push rod part is shown in Figure 6.
4.5. Storage part.
The storage part is equipped with six collection components modules. Each module includes pallets and collection boxes. Each one can store four shuttlecock balls. The collection component is connected with the chain. The chain movement is driven by a motor driving gear to realize the cyclic movement of the collection component. It realizes the collection with twenty-four shuttlecock balls. The wireframe structure of the storage part is shown in Figure 7.

As shown in Figure 7, the collection box is labelled 1 and used to store the shuttlecock balls. Label 2 is the support framework, which could structural support the storage part. The gear is labelled 3 and used to drive and support the chain movement. Label 4 is the main motor. It provides the rotation with the power supply. The centre chain labelled 5 is design to drive the shuttlecock collection box circulation movement.

5. Walking system.
The Mecanum wheels is chosen for the robot walking system with the support plate as shown in Figure 8. As shown in Figure 8, Label 1 is the chassis, which carries the main parts of the machine. Label 2 is the space for placing the spring of the shock absorber. Label 3 is the Mecanum wheels. It could meet the design requirements, such as the volume, weight and size of the robot. Each wheel applies a brushless motor and a two-stage reducer. The rated torque of the motor is expected to be selected as 0.20 Nm with rated speed as 3000 r/min.
6. Control system.
It uses a microcomputer to control the system operation. The shuttlecock ball on the sports field is tested and found by a high-definition camera. After the test is completed, the images will be transmitted to the central processor of the control system. Then the robot walk route is planned to drive the robot walking along the planning path quickly. During the collection process, the function with the mechanical movement control is realized through the infrared ranging sensor, the motors and the actuators.

7. Design verification and simulation

7.1. Running speed.
The standard size of shuttlecock sports field is 11.88 m long and 6.1 m wide. The experimental analysis shows that the actual speed of the shuttlecock collection robot needs as 2.0 m/s. According to the design requirements. Calculation by formula the gear ratio as 3.06. Total transmission ratio as 9.34. The speed of the large gear after deceleration as 321.2 r/min, angular velocity as 33.6 rad/s. The maximum moving speed of the robot is calculated as 2.6 m/s. The maximum speed is larger than that of the robot, which meets the design requirements.

7.2. Torque of driving motor.
Output torque $T$ of driving motor could be calculated by

$$T = \left( \frac{9.55FV}{\eta n} \right)$$

where $F$ is the friction resistance, reference data is 10 N, $\eta$ is the transmission efficiency as 70%, $V$ is the maximum speed of the design robot as 2.6 m/s, $n$ is the speed of the motor as 3000 r/min. We could get $T$ resulted as 0.22 Nm. It shows that the output torque of the driving motor is less than the rated torque, which could meet the design requirements.

7.3. Model simulation.
According to the actual size parameters of the shuttlecock collecting robot, the 3D model is built and assembled in CAD software. To ensure that the design has enough collection efficiency, the motion simulation of the robot working process is carried out through the software. The 20 shuttlecock balls were dropped randomly in the sports field before the simulation starts. Based on the actual working parameters of the robot, the drive was added as the motion simulator. The analysis of the 100 collection process was carried out. The results showed that 20 shuttlecock balls were collected and arranged well in planned operation. The time used by a robot was less than 120 s. Compared with that the time required for the manual collections under the same condition is about 5 minutes, it is far below the efficiency of the robot.

8. Summary
The robot is designed to service shuttlecock sports for the rapid collection of shuttlecock balls. It is composed of the collection part, the transfer part, the carding part, the push rod part and the storage part with the control system. After a detailed introduction to the overall structure and working principle of the robot, the three-dimensional model with the motion simulation are carried out by using the three-dimensional CAD software. The working performance in the real environment of shuttlecock training field is obtained with the collection efficiency. The efficiency is much higher than the manual collection. It could provide an example for research and development of similar products in balls like sports service robots.

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