Ping pong alphago integrated table tennis service robot

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Abstract. In order to achieve multi-dimensional multi-directional launching and intelligent walking functions, the robot can be divided into launching module, angle adjusting module, displacement moving module, ball storage module, collection module and walking module.

1. Introduction
Table tennis as a national fitness exercise, it may not be a one-day thing to learn table tennis well. With the popularization of table tennis, people have higher and higher requirements for table tennis launching robot. At present, table tennis transmitters on the market are more and more difficult to meet people's needs. Therefore, the market urgently needs a diversified and intelligent table tennis training robot.

In response to the needs of the table tennis market in China, an intelligent table tennis robot designed by us has the characteristics of diverse launch, high degree of automation, and high convenience.

Ping-pong AlphaGo robot is a special table tennis robot, its speciality lies in:
1) The existing table tennis transmitter has been improved, so that the device can realize multi-level variable frequency transmission and a variety of spherical transmission functions.
2) The multi-dimensional launch mode enables the device to launch table tennis at any tee, and can better simulate professional table tennis trainers.

Therefore, Ping-pong AlphaGo robot has wide application prospects.

2. Mechanism Design and Principles
The overall structure of the robot is shown in the figure:

Fig. 1 Non-working mode
In order to achieve multi-dimensional multi-directional launching and intelligent walking functions, the robot can be divided into launching module, angle adjusting module, displacement moving module, ball storage module, collection module and walking module.

Fig. 2 Working mode

Fig. 3 Functional breakdown

Fig. 4 Internal exploded view
2.1. Transmitting module

The launch module is mainly composed of motor drive, two-stage friction wheel acceleration mechanism, transmission speed change mechanism, launch tube X-axis swing mechanism.

2.1.1. Multi-stage friction wheel set launching mechanism. In order to achieve control of ball speed and sphericity, we have designed a two-stage friction wheel acceleration adjustment mechanism. The diameter of the first-stage friction wheel d1 is 30mm, which is directly driven by a high-speed DC motor. The design rotation characteristics are high speed and high stability. It is mainly responsible for accelerating the ball and increasing its initial speed. The upper and lower friction wheels 1-2 maintain the same speed ω. The initial speed after acceleration is:

\[ v_1 = \omega \times \frac{d_1}{2} \]

Fig. 5 Two stage friction wheel mechanism

The diameter of the second-stage friction wheel d2 is 40mm, which is transmitted from the first-stage friction wheel by indirect variable speed transmission. The design rotation characteristics are high speed and high frequency conversion. The second-stage friction wheel controls the rotation speed of the upper and lower friction wheels to be different. It adds sphericity to the ball coming from the first stage to achieve spin. When the second-stage friction wheel rotates up and down at a speed of 3-4 \( \omega_3 = \omega_4 \), the table tennis does not rotate, and the final launch speed is:

\[ v = \omega \times \frac{d_2}{2} \]

When the speed of the two-stage friction wheel is \( \omega_3 > \omega_4 \), the ball gets the rotation to wheel 3. When \( \omega_3 < \omega_4 \), the ball gets the rotation in the opposite direction.

\[ v = (\omega_3 + \omega_4) \times \frac{d_2}{4} \]

2.1.2. Transmission gear mechanism. The transmission and transmission mechanism is mainly composed of a bevel gear, a belt pulley and a cam swing lever transmission mechanism. There are two sets of symmetrically distributed on both sides of the ball tube, which are responsible for the transmission between the upper and lower friction wheels 2-3 and 1-4.

Taking a single-sided transmission mechanism as an example, the motor drives the 1-axis output power of the wheel, transmits it to the pulley through the bevel gear, and drives the cam swing lever transmission mechanism. The transmission ratio of the bevel gear is 1:1, and the transmission ratio of the pulley is 1:2.

The mechanism is composed of input and output shaft, planetary gear transmission, three cams, three swing bars, three arc pressing plates and overrunning clutch, which make up of three independent groups of cam swing bar mechanism. Three cam intervals are installed on the camshaft corresponding to three swing bars.
The stepless speed change mechanism of cam swing rod can realize stepless speed change by adjusting the axial relative position of swing rod. It has small volume, few parts, exquisite structure and precise transmission. It can better realize stepless speed change between two-stage friction wheels.

After the output power of cam swing bar CVT mechanism is transmitted by pulley bevel gear, the power is input into pulley 4. The differential rotation of the friction wheels 3 and 4 can be realized by changing the transmission ratio on both sides of the transmission device.

x.x emission tube x-axis swing mechanism

The gear located at the root of the transmitting tube is driven by the motor gear to realize the rotation of the whole transmitting tube along the x-axis. With the x-axis rotation of the launch tube and the differential rotation of the friction wheels 3 and 4, any rotating ball can be launched to better control the ball performance.

The cross section diameter of the launch tube is slightly larger than that of table tennis, and there are four axial guide rails inside. Table tennis does not directly contact with the tube wall, which reduces the energy loss caused by friction during the movement of table tennis in the tube and reduces the adverse effect of the tube wall on the spinning ball.

2.2. Angle adjustment module

The angle adjustment module is composed of a pitch adjustment device and a yaw adjustment device.

2.2.1. Pitch adjustment. In order to realize the pitch adjustment function of the launching port, the device uses a guide rod mechanism, which uses a motor as the output power, decelerates through a gear set, and drives the crank to rotate the launcher fixed to the end of the guide rod to rotate around the axis.

2.2.2. Yaw adjustment device. The horizontal swing device uses the spatial crank slider mechanism, which drives the slider to move along the chute through the crank rotation, so that the chute rotates along the shaft, and the upper device which is fixedly connected with the chute swings along the shaft driven by the chute. At the same time, a pair of reduction gears are installed to reduce the speed and increase the torque of the mechanism to undertake the weight of the upper transmission port.
2.3. Ball storage module

The ball storage module is mainly composed of a rotating ball storage cylinder, a rotating device, a lifting device and a clamping device;

A total of three ball storage tanks of the ball storage module are located on the fixed angle rotating device. When the robot starts to move, the rotating device rotates the ball storage module under the lifting device. The lifting device works to send the ball storage tank to the lower part of the launching module, and the clamping device clamps the clamping hands on both sides of the ball storage tank to fix the ball storage tank and start to release the ball.

Fig. 8 Ball storage module

2.3.1. Annular reservoir. Table tennis is stored in the sub spherical storage tank, and the lifting seat is lifted upward through the lead screw drive to realize the transportation of table tennis. When the sub spherical storage port has finished feeding the ball, the motor drives the worm wheel to make the
grooved wheel mechanism work, so that the sub spherical storage tank fixed on the grooved wheel mechanism rotates and enters the next spherical storage port.

2.3.2. Rotating rotation device. The rotating rotation device is mainly composed of the groove wheel mechanism and the crank slider mechanism, and the annular ball storage cylinder is placed on the rotation device. Through the groove wheel mechanism, three annular spherical tanks rotate at 60 degrees. In order to make the storage tank connected stably, the crank slider is driven by the motor to fix the storage tank.

2.3.3. Lifting device. The lifting device uses a shearing fork mechanism. The shearing fork mechanism is powered by a motor. The rotation of the motor causes the screw rod to drive the slider to move.

3. Determination of calculation size and strength check

3.1. Gear design of head moving mechanism

1) Selection of gear materials
Because the head moving mechanism requires fast speed, it requires stable transmission, low noise and high speed. Therefore, the high-speed gear is selected, and the alloy steel is selected as the material. The form is straight cylindrical gear, so the gear is alloy steel high-speed gear. According to the table, the fatigue limit of this material is as follows:

\[ \sigma_{F1} = \sigma_{F2} = 450 \text{MPa} \]
\[ \sigma_{H1} = \sigma_{H2} = 1500 \text{MPa} \]

2) Design according to the bending fatigue strength of tooth root

Calculate the torque transmitted by gear 1:

\[ T_1 = \frac{95.5 \times 10^5 P}{n} = \frac{95.5 \times 10^5 \times 5 \times 10^{-3}}{240} \approx 199 N \cdot mm \]

Determine the bending fatigue strength of two gears:

According to the table of bending fatigue limit stress of alloy steel gear, we can get:

\[ \sigma_{F01} = \sigma_{F02} = 450 \text{MPa} \]
\[ M_1 = \frac{nL \times 60}{10^6} = \frac{240 \times 3000 \times 60}{10^6} = 43.2 \]

Therefore, the life factor is:

\[ Y_{N1} = Y_{N2} = 1 - \frac{\log 43.2}{5} = 0.67 \]

Available, ultimate strength:

\[ \sigma_{F1} = \sigma_{F01} Y_{K1} Y_{N1} = 450 \times 1 \times 0.67 = 301.5 \text{MPa} \]
\[ \sigma_{F2} = \sigma_{F02} Y_{K2} Y_{N2} = 450 \times 1 \times 0.67 = 301.5 \text{MPa} \]

3.2. Design and check of gear shaft of launch module
1) Select the material of the shaft
   In this transmission system, the pinion shaft has no special requirements, so the material of the shaft is quenched and tempered 45 # steel. According to the table, \( \sigma_B = 640 \text{MPa} \).

2) Preliminary determination of the minimum diameter of the shaft
   It can be seen from the above calculation that the power transmitted by the gear shaft is \( P = 0.3w \), and the rotational speed of the gear shaft is \( n = 60 \text{r/min} \). According to the table, \( C = 110 \) is taken, so:
   \[
   d_{\min} \geq C \sqrt[3]{\frac{P}{n}} = 110 \times \sqrt[3]{\frac{0.3}{60}} = 22.3 \text{mm}
   \]
   In order to facilitate processing, \( d_{\min} = 25 \text{mm} \) is taken.

3) Structural design of shaft
   Determine the diameter and length of each section of the shaft according to the requirements of axial positioning
   A. In order to connect the first section with the coupling, the length is designed according to the size of the coupling, and the shaft diameter \( D_1 = 25 \text{mm} \), \( L_1 = 12 \text{mm} \);
   B. The second section of shaft is taken as the transition shaft section, and the shaft diameter \( D_2 \) is taken as \( 27 \text{mm} \), \( L_2 = 15 \text{mm} \)
   C. The third section is mainly matched with the rolling bearing, so its length has positioning accuracy requirements, so the design results show that the diameter of the third section is \( D_3 = 30 \text{mm} \), \( L_3 = 30 \text{mm} \)
   D. The fourth and second paragraphs are identical.
   E. The shaft diameter of the fifth section is exactly the same as that of the first section.

4) Circumferential positioning of parts on shaft
   The positioning on the shaft is to install the gear on the shaft with M3 screw, and fix the gear to prevent it from being thrown out due to motion inertia.

5) Load distribution on shaft
   Magnitude of gear force:
   According to the above calculation, the power transmitted by the gear is:
   \[
   P_1 = P_{L1} \eta_{bearing} = 0.3 \times 0.94 = 0.282w
   \]
   The torque is:
   \[
   T_1 = 9550 \frac{P_1}{n_1} = 9550 \times \frac{0.282 \times 10^{-3}}{90} = 0.030N \cdot m
   \]
Circumferential force:

\[ F_{t1} = \frac{2T_1}{d_1} = \frac{2 \times 0.030}{0.04} = 1.5N \]

Radial force:

\[ F_{r1} = F_{t1} tan\alpha = 1.5 \times tan20^\circ = 0.55N \]

As shown in the figure, a and C are the fulcrum of the two rolling bearings, and B is the force point of the gear against the shaft.

Bending moment diagram:

\[ M_{sun} = \sqrt{M_{X-Z}^2 + M_{X-Y}^2} = \sqrt{13.6^2 + 85.1^2} = 86N \cdot mm \]

6) Check the strength of the shaft according to the combined bending and torsion stress

When checking, generally only the section bearing the maximum bending moment and torque on the shaft is checked. As the shaft rotates in one direction, the torsional shear stress is fluctuating cyclic variable stress. Take \( \alpha = 0.6 \), and the calculated stress of the shaft is:

\[ \sigma_{ca} = \frac{\sqrt{M^2 + (\alpha T)^2}}{W} = \frac{\sqrt{86^2 + (0.6 \times 80)^2}}{0.1 \times 15^3} = 0.29MPa \]
The material of the shaft has been selected as quenched and tempered 45 steel. According to the table, $[\sigma_{-1}] = 60\text{MPa}$ can be seen. Therefore, $\sigma_{ca} < [\sigma_{-1}]$ is safe.

4. Conclusion

Our robot has a variety of angle adjustment launch mode, various functions, can be applied to various scenes, can be applied to different age groups and different levels of crowd training, has a broad market prospect. The overall design of the device is humanized: the device has complete functions, which can effectively reduce the manual operation steps and work intensity; the device has strong applicability: strong popularization; the device principle is simple, and the cost of each component is low. Compared with the existing table tennis robot, the device has more complete functions and is easy to promote.

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