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Intelligent Recognition System for the Curves Trajectory and Track Capture Using Artificial Intelligence Technology

基于人工智能技术的曲线轨迹智能识别系统与轨迹捕捉

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Abstract. Aiming at the problem of large deviation of the recognition results of the traditional recognition system, this article carried out the design and research of the intelligent recognition system of the football curve ball movement trajectory. The hardware structure design includes the acceleration sensor selection, the angular motion detection device selection and the power supply circuit design, and the software structure design includes the motion trajectory data filtering processing and the football curve ball motion speed displacement recognition. Experiments show that, compared with the traditional system, the design system has a smaller deviation of the recognition results, significantly fewer recognition errors, and higher accuracy.

摘要。针对传统识别系统识别结果偏差大的问题，本文开展了足球曲线球运动轨迹智能识别系统

的设计与研究。硬件结构设计包括加速度传感器选型、角运动检测装置选型和电源电路设计，软件结构设计包括运动轨迹数据滤波处理和足球曲线球运动速度位移识别。实验表明，与传统系统相比，设计系统的识别结果偏差更小，识别错误明显更少，准确性更高。

Keywords: Artificial intelligence technology, football training, motion trajectory capture, training assistance.

关键词：人工智能技术、足球训练、运动轨迹捕捉、训练辅助。

1. Introduction

1. 引言

When discussing oblique throwing motion in current college physics textbooks, mass points are the research objects, and the oblique throwing motion of rotating objects is rarely involved. In fact, the movement of rotating projectiles is a very common phenomenon, especially in ball sports, when the sphere is moving in the air, it is often accompanied by rotation, such as: football, table tennis, basketball and tennis. The rotation of the sphere itself will inevitably affect its trajectory, that is to say, in this case, the Magnus effect needs to be considered. When a cylinder rotates around its axis and a fluid flows in a direction perpendicular to the axis, it will receive a transverse force perpendicular to the direction of flow. The direction of the force always points from the direction of flow to the side opposite to the linear velocity on the surface of the cylinder. On the same side, this phenomenon is called the Magnus effect, and some scholars write it as the Magnus effect. At present, the system for recognizing motion trajectories mainly uses image gray information to segment images in video sequences [1]. But this kind of system ignores the original colour information of the image when recognizing the trajectory of the football curve ball, so the recognition results often have problems such as large errors and slow recognition speed. In response to the above problems, this paper proposes a new intelligent recognition system for the trajectory of the football curve by analysing the football curve ball movement.

在当前大学物理教材中讨论斜抛运动时，研究对象是质点，很少涉及旋转物体的斜抛运动。实际上，旋转抛体的运动是一种非常常见的现象，尤其是在球类运动中，球体在空中运动时，往往伴随着旋转，比如：足球、乒乓球、篮球和网球。球体自身的旋转必然会影响其轨迹，也就是说，在这种情况下，需要考虑马格努斯效应。当圆柱体绕其轴线旋转且流体沿垂直于轴线的方向流动

时，它会受到一个垂直于流动方向的横向力。力的方向总是从流动方向指向圆柱体表面线速度相反的一侧。在同一侧，这种现象称为马格努斯效应，一些学者将其写成Magnus效应。目前，运动轨迹识别系统主要利用图像灰度信息对视频序列中的图像进行分割[1]。但这种系统在识别足球曲线球轨迹时忽略了图像的原始颜色信息，所以识别结果往往存在误差大、识别速度慢等问题。针对上述问题，本文通过分析足球曲线球运动，提出了一种新的足球曲线轨迹智能识别系统。

2. Theoretical basis

2. 理论基础

2.1. Bernoulli principle

2.1. 伯努利原理

Bernoulli's principle: The Swiss mathematician Daniel Bernoulli put forward the theorem that is now widely known. P is the pressure at a certain point in the airflow, ρ is the airflow density,and V is the velocity at a certain point in the airflow.

伯努利原理：瑞士数学家丹尼尔·伯努利提出了如今广为人知的定理。P 是气流中某一点的压力，ρ 是气流密度，V 是气流中某一点的速度。

$$p + \frac{1}{2}\rho V^2 = C \qquad (1)$$

2.2. Magnus effect

2.2. 马格努斯效应

According to Bernoulli's principle, a ball with a curved trajectory must be rotated, and the lateral force that causes the trajectory of the ball to bend is generated by the rotation of the ball [2]. When rotating, it produces asymmetrical airflow, which produces lift or lateral force, which is perpendicular to the direction of the axis of rotation. It can be seen from Figure 1 that a rotating ball will deflect upward or laterally due to the difference in its axis of rotation.

根据伯努利原理，具有弯曲轨迹的球必须旋转，使球的轨迹弯曲的侧向力是由球的旋转产生的

[2]。旋转时，它会产生不对称气流，从而产生升力或侧向力，该力垂直于旋转轴方向。从图1可以看出，旋转的球会因其旋转轴的差异而向上或侧向偏转。

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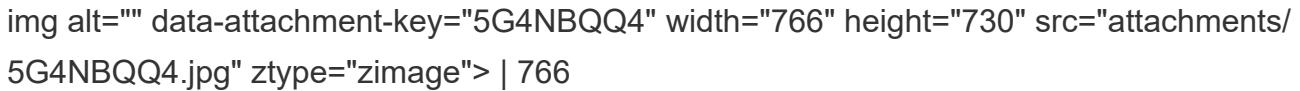
Figure 1. Football Bernoulli Principle

图1. 足球伯努利原理

2.3. Football force

2.3. 足球受力

The forces on a football are gravity, air resistance, and Magnus force due to the rotation of the ball. The Magnus force is just opposite to the direction of gravity, which is an upward force.

足球受到的力有重力、空气阻力以及由于球的旋转产生的马格努斯力。马格努斯力与重力方向相反，是一个向上的力。

Some scholars pointed out that the aerodynamic force of a moving object is determined by the surface characteristics of the object itself, the area exposed to the air, the air velocity, and the pressure. They gave the formula for the force of any moving object in the air: D is the air resistance, F_{mag} is the Magnus force received, C_d is the drag coefficient, C_{mag} is the Magnus force coefficient, A is the projected area of the sphere in the air, and v is the relative flow velocity.

一些学者指出，运动物体的空气动力由物体本身的表面特性、暴露在空气中的面积、空气速度和压力决定。他们给出了任何运动物体在空气中受力的公式：D 是空气阻力，F_{mag} 是受到的马格努斯力，C_d 是阻力系数，C_{mag} 是马格努斯力系数，A 是球体在空气中的投影面积，v 是相对流速。

$$D = -\frac{1}{2}C_d \rho A |v|^2 \frac{v}{|v|} \qquad (2)$$

$$F_{mag} = \frac{1}{2}C_{mag} \rho A |v|^2 \frac{\omega \times v}{|\omega \times v|} \qquad (3)$$

2.4.The drag coefficient and Magnus force coefficient of the sphere system

2.4. 球体系统的阻力系数和马格努斯力系数

The drag coefficient is related to the density and speed of the airflow, and the resistance on the projection surface of the sphere. But for the same object, the difference in drag coefficient is directly related to the Reynolds number. Some scholars have found that the size of the Reynolds coefficient is related to the smoothness of the surface of the object and the speed of the object. Therefore, the faster the sphere, the more likely it is that the turbulence resistance is lower.

阻力系数与气流的密度和速度以及球体投影面上的阻力有关。但对于同一物体，阻力系数的差异直接与雷诺数有关。一些学者发现，雷诺系数的大小与物体表面的光滑程度和物体的速度有关。因此，球体速度越快，湍流阻力越低的可能性就越大。

C_d decreases with the increase of Re. At the critical point, C_d will suddenly drop a lot. This phenomenon occurs because under critical conditions, the airflow will suddenly turn into turbulent flow, and the airflow streamlines will be separated, and the resistance will be greatly reduced in an instant.

C_d 随Re的增加而减小。在临界点，C_d 会突然大幅下降。出现这种现象是因为在临界条件下，气流会突然变成湍流，气流流线会分离，阻力会瞬间大幅降低。

Like the drag coefficient, the Magnus force coefficient of the sphere system is also related to the airflow density, speed, and the projected area of the object [3]. The theoretical Magnus force coefficient of a non-rotating ball is zero, so we only discuss the influence of the rotation of the ball on the Magnus force coefficient. Regarding a rotating ball, regardless of its rotation direction, it generates Magnus force, which changes the ball's trajectory and produces a curved ball.

与阻力系数一样，球体系统的马格努斯力系数也与气流密度、速度以及物体的投影面积有关[3]。非旋转球的理论马格努斯力系数为零，所以我们只讨论球的旋转对马格努斯力系数的影响。对于旋转的球，无论其旋转方向如何，都会产生马格努斯力，从而改变球的轨迹并产生弧线球。

2.5.The acceleration equation when the ball is flying in the air

2.5. 球在空中飞行时的加速度方程

When we consider gravity, Magnus force and air resistance, the vector equation of motion is:

当我们考虑重力、马格努斯力和空气阻力时，运动的矢量方程为：

$$a = \frac{F_{\mathrm{mag}}}{m} + \frac{D}{m} + g \qquad (4)$$

Bring in F_{mag} and D to get:

代入F_{mag} 和D 可得：

$$a = \frac{1}{2}\frac{C_{mag}\rho A|v|^2 \frac{\omega \times v}{|\omega \times v|}}{m} - \frac{1}{2}\frac{C_{\mathrm{d}}\rho A|v|^2 \frac{v}{|v|}}{m} + g \qquad (5)$$

Among them,a is the acceleration of the sphere movement, m is the mass of the sphere,and g is the acceleration due to gravity. The equation for the acceleration of the sphere flying in the air has been given. For a determined sphere,due to the uncertainty of ρ in the environment and the uncertainty of the two parameters $\mathrm{C}_{\mathrm{mag}}$, C_{d} and,we cannot give a simpler formula Equation. Under the existing conditions, the author cannot give more explanations and descriptions about this equation [4]. When there are better conditions in the future, I hope that a computer can be used to simulate this equation and give more graphical explanations.

其中，a为球体运动的加速度，m为球体的质量，g为重力加速度。已经给出了球体在空中飞行时加速度的方程。对于一个确定的球体，由于环境中ρ的不确定性以及两个参数$\mathrm{C}_{\mathrm{mag}}$，$\mathrm{C}_{\mathrm{d}}$的不确定性，我们无法给出更简单的公式方程。在现有条件下，作者无法对该方程给出更多解释和描述[4]。未来有更好的条件时，希望可以用计算机模拟这个方程并给出更多图形解释。

3. Design of intelligent capture system for football trajectory

3. 足球轨迹智能捕捉系统设计

3.1. System hardware design

3.1. 系统硬件设计

3.1.1. Selection of acceleration sensor. Because the arc of football is a three-dimensional moving object in space, and athletes usually participate in the process of football, its moving range is small. According to this feature, this article chooses KSD-2563 model acceleration sensor.

3.1.1. 加速度传感器的选择。由于足球的弧线是空间中的三维运动物体，并且运动员在参与足球运动过程中其运动范围较小。根据这一特点，本文选用KSD - 2563型号加速度传感器。

3.1.2. Selection of angular motion detection device. The SJDA-25542 angular motion detection device can provide the system with digitally adjustable sensor data through a simple serial interface, and the serial interface can provide access to the angular motion detection device, temperature, and power supply voltage measurement [5]. According to the vibration coupling of the angular motion detection device in the driving mode, by detecting the displacement or corresponding change of the angular motion detection device in the detection mode, it is obtained that the angle of the football curve ball is large.

3.1.2. 角运动检测装置的选择。SJDA - 25542角运动检测装置可以通过简单的串行接口为系统提供数字可调的传感器数据，并且该串行接口可以提供对角运动检测装置、温度以及电源电压测量的访问[5]。根据角运动检测装置在驱动模式下的振动耦合，通过检测角运动检测装置在检测模式下的位移或相应变化，得出足球香蕉球的角度较大。

3.1.3. Power circuit design. The mobile terminal of the system in this paper uses a 4.0V button battery to provide power, and the base station uses a 4C external power supply. The operating voltage of the above acceleration sensor device during operation is 3.5V, and the operating voltage of the angular motion detection device during exercise is 4.5V. According to the system operation needs of this article, the regulated power supply model is designed to meet the

working voltage of different hardware devices. Figure 2 is a schematic diagram of the connection of the system power circuit in this article.

3.1.3. 电源电路设计。本文系统的移动终端使用4.0V纽扣电池供电，基站使用4C外部电源。上述加速度传感器装置在运行时的工作电压为3.5V，角运动检测装置在运动时的工作电压为4.5V。根据本文的系统运行需求，设计稳压电源模型以满足不同硬件设备的工作电压。图2为本文章系统电源电路连接示意图。

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Figure 2. Schematic diagram of the system power circuit connection in this article

图2. 本文章系统电源电路连接示意图

3.2. System software design

3.2. 系统软件设计

Input the speed and displacement data recognized by the system into MATLAB software to complete the drawing of the three-dimensional trajectory of the football curve ball, and realize the intelligent recognition of its motion trajectory.

将系统识别出的速度和位移数据输入到MATLAB软件中，完成足球香蕉球三维轨迹的绘制，并实现对其运动轨迹的智能识别。

4. Application of the model to specific phenomena

4. 模型在具体现象中的应用

According to international standards, we take the parameters of football as shown in Table 1.

根据国际标准，我们采用表1所示的足球参数。

Table 1. Football parameters

表1. 足球参数

Diameter	Quality	Goal specifications	Distance from penalty area line to goal line	Air density
69cm	430g	7.32m×2.44m	16.5m	1.25kg/cubic meter

Brazilian player Didi invented the elevator ball (also known as the deciduous ball), and the representatives of the deciduous ball in today's football include Pirlo, Cristiano Ronaldo and so on. This article will take Cristiano Ronaldo's elevator ball as an example to study the trajectory of the elevator ball and the reason why the ball plunges before it falls into the goal. I use the free kick mode in the game of live football to help us build an intuitive model. Figure 3 is a computer simulation of Cristiano Ronaldo's free kick situation.

巴西球员迪迪发明了电梯球（又称落叶球），当今足球界落叶球的代表人物包括皮尔洛、克里斯蒂亚诺·罗纳尔多等。本文将以克里斯蒂亚诺·罗纳尔多的电梯球为例，研究电梯球的轨迹以及球在落入球门之前下坠的原因。我使用实况足球游戏中的任意球模式来帮助我们建立一个直观的模型。图3是克里斯蒂亚诺·罗纳尔多任意球情况的计算机模拟。
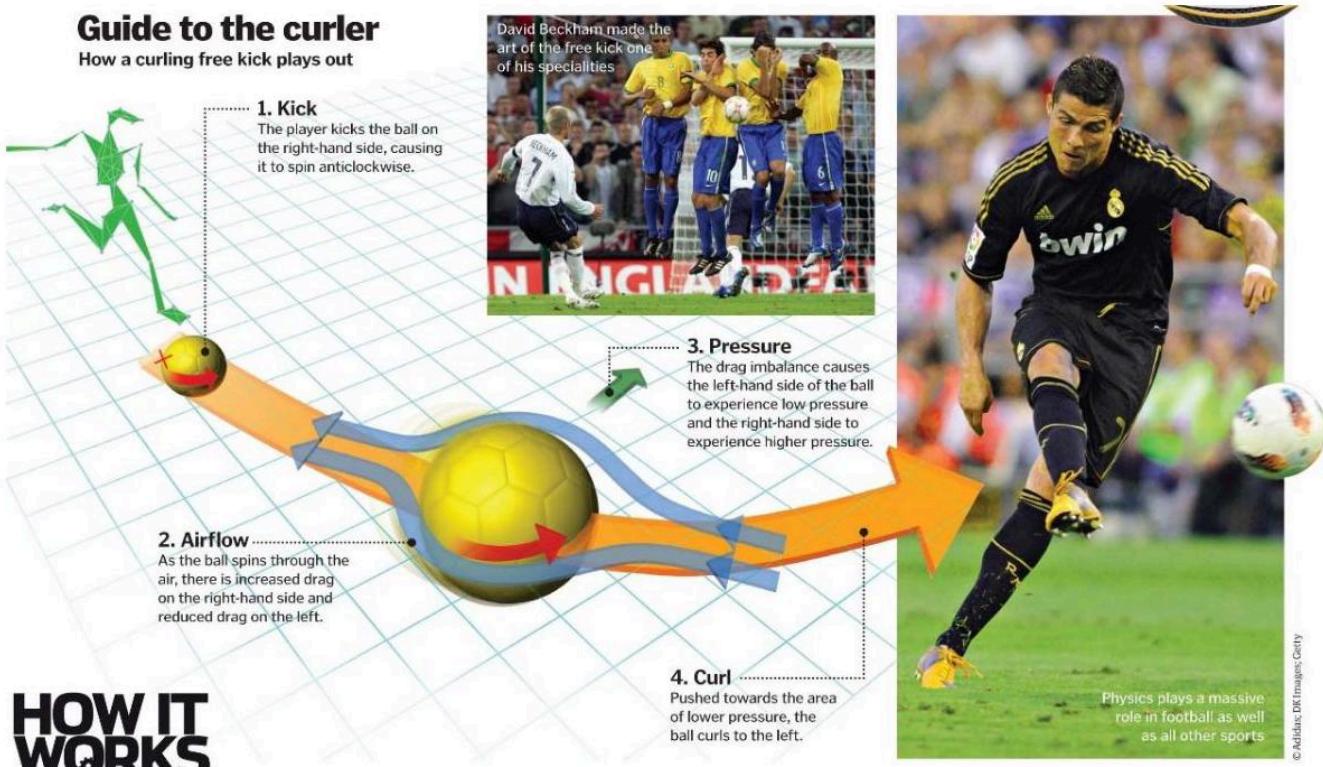

Figure 3. Computer simulation of Cristiano Ronaldo's free kick situation

图3. 克里斯蒂亚诺·罗纳尔多任意球情况的计算机模拟

According to Cristiano Ronaldo's free kick style, we chose his best 23m distance to study his free kick trajectory. The deciduous ball in this way has almost no lateral rotation and has a certain amount of external rotation [6]. No side spin means that the ball will not have a lateral arc. We simplified the flight trajectory of his entire ball into a plane motion (Figure 4).

根据克里斯蒂亚诺·罗纳尔多的任意球风格，我们选择他最佳的23米距离来研究他的任意球轨迹。这样的落叶球几乎没有横向旋转，有一定的外旋[6]。没有侧旋意味着球不会有横向弧线。我们将他整个球的飞行轨迹简化为平面运动（图4）。
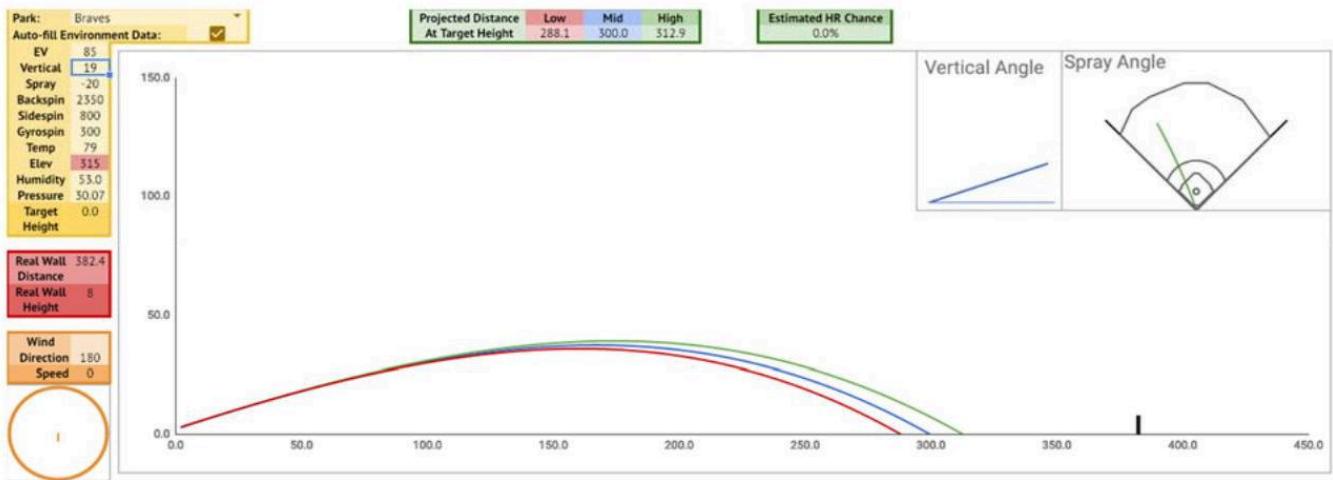

Figure 4. Ideal flight trajectory diagram of elevator ball

图4. 电梯球理想飞行轨迹图

In (2),the air resistance coefficient C_d is directly related to Re. In Anderson's research,the Re of football is about 2.5×10^5 . so,the formula (2) is simplified to:

在(2)中，空气阻力系数C_d与雷诺数直接相关。在安德森的研究中，足球的雷诺数约为2.5×10^5。因此，公式(2)简化为:

$$D = -0.13\rho A|v|^2 \frac{v}{|v|} \qquad (6)$$

In the formula (3), R is the radius $C_{\mathrm{mag}} = \frac{2\omega R}{v}$ of the sphere,so the formula (3) is simplified to:

在公式(3)中，R是球体的半径$C_{\mathrm{mag}} = \frac{2\omega R}{v}$，所以公式(3)简化为:

$$F_{\mathrm{mag}} = \frac{\omega R}{v}\rho A|v|^2 \frac{\omega \times v}{|\omega \times v|} \qquad (7)$$

We only study the two-dimensional motion, decompose the speed in the x and y directions,

and only consider the angular velocity of the z axis:

我们仅研究二维运动，将速度分解为x和y方向，并仅考虑z轴的角速度：

$$v = \sqrt{v_x^2 + v_y^2} \qquad (8)$$

$$\omega = \omega_z$$

Various data show that the speed of a very high-speed free kick can be as high as 120 km/h ,and in some cases, it can even reach 200km/h . We assume that Cristiano Ronaldo's ball speed is 100 km/h ,that is, the average speed is 27 m/s . Due to the characteristics of Cristiano Ronaldo's free kick,we assume that it is non-spinning,that is $\omega = 0$. Under such a setting,we turn Eq. (5) into its simplest form:

各种数据表明，非常高速的任意球速度可高达120 km/h，在某些情况下，甚至可达到200km/h。我们假设克里斯蒂亚诺·罗纳尔多的球速为100 km/h，即平均速度为27 m/s。由于克里斯蒂亚诺·罗纳尔多任意球的特点，我们假设其不旋转，即$\omega = 0$。在这种设定下，我们将式(5)化为其最简形式：

$$a = -0.13 \frac{\rho A |v|^2 \frac{v}{|v|}}{m} + g \qquad (9)$$

Bring in ρ, A, m to get

代入ρ, A, m得到

(10)

$$a \approx -0.05 \left| v \right| v + g$$

$$\rho = 1.25 \text{ kg/m}^3$$

Solve for both x and y directions

求解x和y两个方向

$$\frac{dv_x}{dt} = 0.05 v_x \sqrt{v_x^2 + v_y^2} \qquad (11)$$

$$\frac{dv_y}{dt} = 0.05 v_y \sqrt{v_x^2 + v_y^2} + g \qquad (12)$$

There is no analytical solution to this equation, so I use computer graphics. Assuming that the

initial speed of the ball is 30 m/s ,since the angle of the foot cannot be determined,the computer simulates the possible trajectory of different angles of the foot under this equation, as shown in Figure 5 below.

此方程没有解析解，所以我使用计算机图形学。假设球的初始速度为30 m/s，由于脚的角度无法确定，计算机在此方程下模拟脚不同角度的可能轨迹，如下方图5所示。
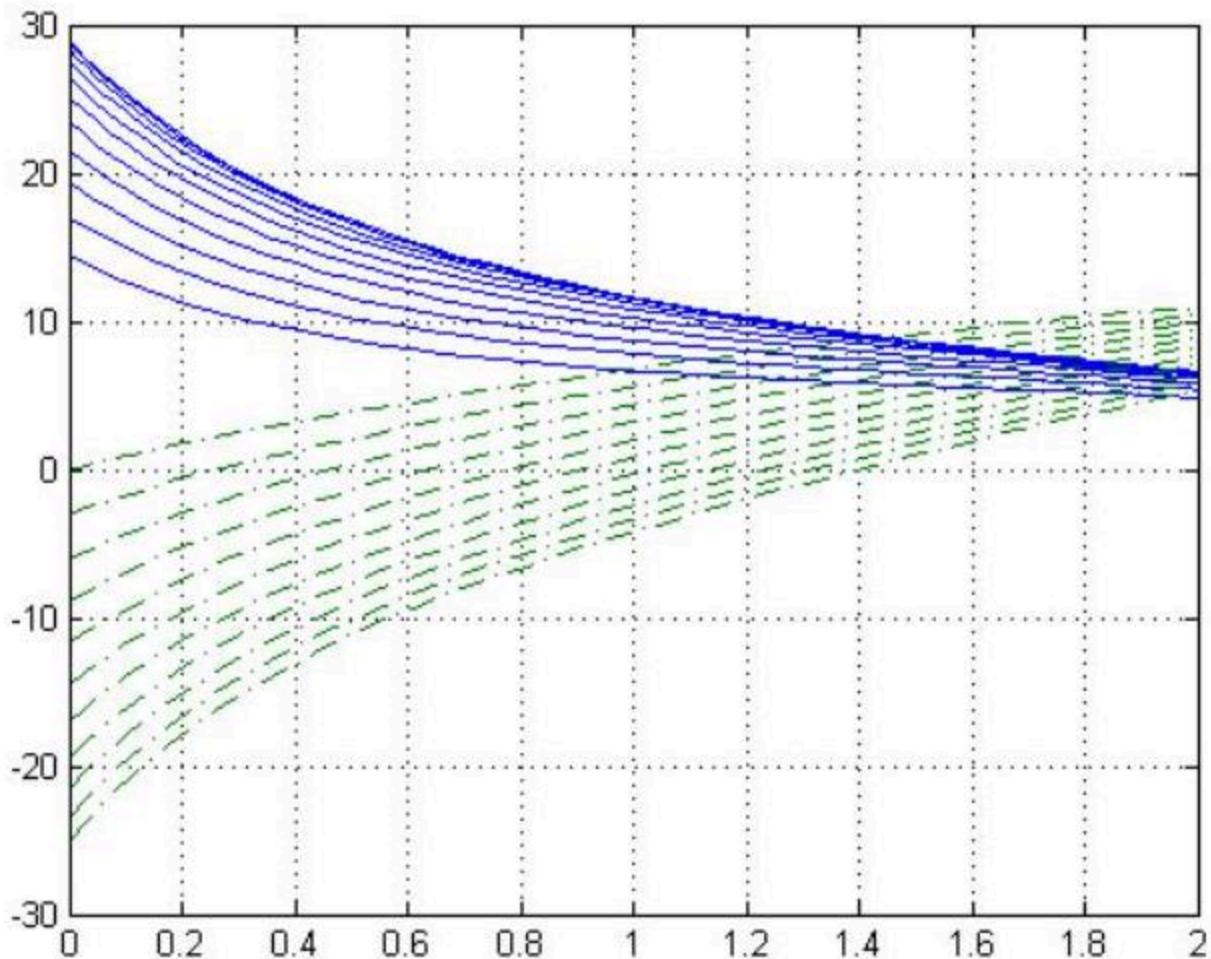
Figure 5. Computer simulation of the trajectory under different angles

图5.不同角度下轨迹的计算机模拟

The above picture is a simulation of the trajectory when the ball exit angle is 30 degrees. From the picture, it can be seen that the ball falls to the lowest point approximately at 23m, which can just fall into the goal and successfully bypass the wall. The trajectory is approximately in line with the actual situation. It can be considered that the given equations (11) and (12) are referenced to a certain extent. However, the Magnus force is not used in this discussion, which is the neglected force among the three forces. Due to the characteristics of the elevator ball,

the Magnus force is very small due to the small rotation, which does not have much influence on the discussion of the trajectory.

上图是球出射角度为30度时轨迹的模拟。从图中可以看出，球大约在23米处落至最低点，刚好能落入球门并成功绕过人墙。该轨迹大致符合实际情况。可以认为所给的方程(11)和(12)在一定程度上是可参考的。然而，本讨论中未使用马格努斯力，它是这三种力中被忽略的力。由于电梯球的特点，因旋转小，马格努斯力非常小，对轨迹讨论影响不大。

5. Conclusion

5.结论

In this paper, combining the law of football curve ball movement, a new intelligent recognition system of football curve ball movement trajectory is proposed. While realizing the movement trajectory recognition, the relevant software and hardware are explained in detail, and the performance of the system is proved through experiments. In the follow-up research, the system's recognition accuracy will be further studied, so as to realize the centimetre or even millimetre-level recognition of the football curve ball movement trajectory.

本文结合足球弧线球运动规律，提出了一种新的足球弧线球运动轨迹智能识别系统。在实现运动轨迹识别的同时，详细说明了相关软硬件，并通过实验证明了系统的性能。在后续研究中，将进一步研究系统的识别精度，以实现对足球弧线球运动轨迹厘米甚至毫米级的识别。

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