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Action Design of Lobbing Ball for Humanoid Robot Soccer

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Abstract. Robot soccer is a classic research direction in the field of robotics. From the appearance of soccer robot, it is mainly divided into wheeled robot and humanoid robot. At present, humanoid robots and small group wheeled robots mainly compete on two-dimensional plane. Because of the small competitive dimension, the offensive and defensive tactics tend to be simple. In order to enhance the competitiveness and appreciation of humanoid. And complex motion devices based on human motion capture data (HMCD) are designed Human simulation has gradually become one of the effective means of robot design. In order to enhance the competitiveness and appreciation of humanoid, this paper innovatively designs a set of consistent kicking actions based on darwin-op2 robot, combined with HMCD method, realizes the effect of actively lobbing ball. Ideally, the robot can basically kick the ball above 35cm. Besides the robot can basically kick the ball above 30cm in practice, and the success rate is as high as 75%. It improves the competitiveness from two-dimensional to three-dimensional, which provides new ideas and schemes for attack and defense tactics and expands the dimension of competition. It also provides a new direction for the development of humanoid robot football in the future.

Keywords: humanoid robot, HMCD, robot soccer competition, batting action, lobbing ball

1 Introduction

Robot soccer competition is a classic research direction in the field of robotics, which provides a comprehensive robot research platform with dynamic antagonism. From the appearance of robots, soccer robots are mainly divided into wheeled robots [1] and humanoid robots. The competition of wheeled robot soccer is divided into small group and medium group. At present, the medium group is a three-dimensional competition. In the process of competition, the robot can kick the ball into the air actively, cross the enemy robot and its defense in front of it, and achieve the effect of lobbing ball penetration, passing and shooting. Because the competition is three-dimensional, its offensive and defensive tactics are diverse, flexible, competitive and ornamental. However, at present, humanoid robots and small wheeled robots can't kick the football into the air autonomously in the game to achieve lobbing ball defense, passing and shooting. This results in the situation that robots can only compete in the two-dimensional plane in all major competitions, which leads to the simplicity of attack and defense, and the monotony of competitiveness and appreciation.

RoboCup [2-3] is a worldwide competition in which autonomous robots play soccer against each other, with the ultimate goal of beating the human world champion team in 2050. There are different leagues, including the small-size league, the mid-size league and humanoid league. In the latter, robots should walk as opposed to the small-size and midsize league where they are wheeled. In 2006, S. Behnke [4] use kidsize robot to win the penalty kick and ranked second in the overall ranking of the best human shape.

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For robot soccer control, De Best J [5] describes a new active ball handling method for the RoboCup mid-size league as used by team Tech United at Eindhoven University of Technology. A theoretical model is derived followed by the control design including a feedback controller and a feedforward controller. describes a new active ball handling method for the RoboCup mid-size league, which showed the effectiveness of the new ball handling design. Deng [6] desigened the joint debugging and simulation platform of Kinect and Darwin-OP2 humanoid robot for imitation learning. The platform mainly includes image acquisition module, motion control module and 3D model simulation module, which has the functions of human body attitude solution, robot real-time condition monitoring and attitude simulation, communication with the lower computer through network and remote real-time tracking control.

In order to improve the competitiveness of humanoid robot soccer from two-dimensional to three-dimensional, and increase the flexibility of offensive and defensive tactics, this paper starts with the action of human soccer, analyzes and studies the key actions, and designs a set of consistent kicking actions based on darwin-op2 robot. Under the premise of abiding by the rules of the game, it realizes the effect of robot actively lobbing ball.

2 Soccer Humanoid League Rules

2.1 The Field of Play

The competitions [2] take place on a rectangular field, which contains two goals and field lines, as shown in Fig. 1. The parameter display in Table 1.

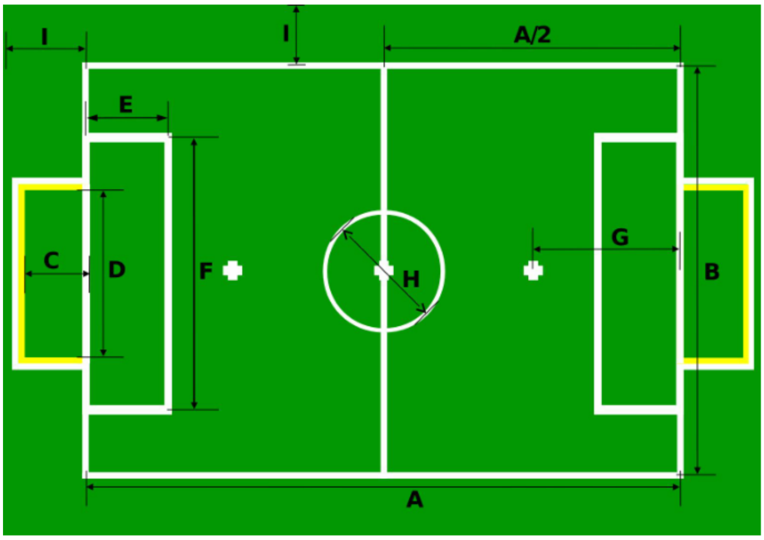

Fig. 1. Humanoid robot soccer field (not to scale)

Table 1. The dimensions of the rectangular field of soccer play (in cm)

		Size
A	Field length	600
B	Field width	400
C	Goal depth	50
D	Goal width	150
E	Goal area length	60
F	Goal area width	220
G	Penalty mark distance	180
H	Center circle diameter	120
I	Border strip width (min.)	70

The field consists of a flat and even ground which is covered with green carpet. The white lines are 5 cm wide. Line segments of 10 cm length are used to denote penalty mark and the kick-off position (center mark). The longer outer field lines are called touch lines, whereas the shorter outer field lines are called goal lines. The field is surrounded by a border strip, which is also covered with green carpet. The world outside the border strip is undefined. Around the field of play (Fig. 1) a field zone is defined on site in which only the referee (Section 5), the assistant referees (Section 6) and the two robot handlers are allowed to stay during the game. All persons in the field zone must not show colors below their waist that are the same as or similar to any of the defined colors on the field. The field zone must give sufficient space to the referees and robot handlers for passing behind the goals. All other people (including other team members, organizational staff, representatives of the press and the media etc.) must stay outside the field zone. The aerial view of the site is as Fig. 2.

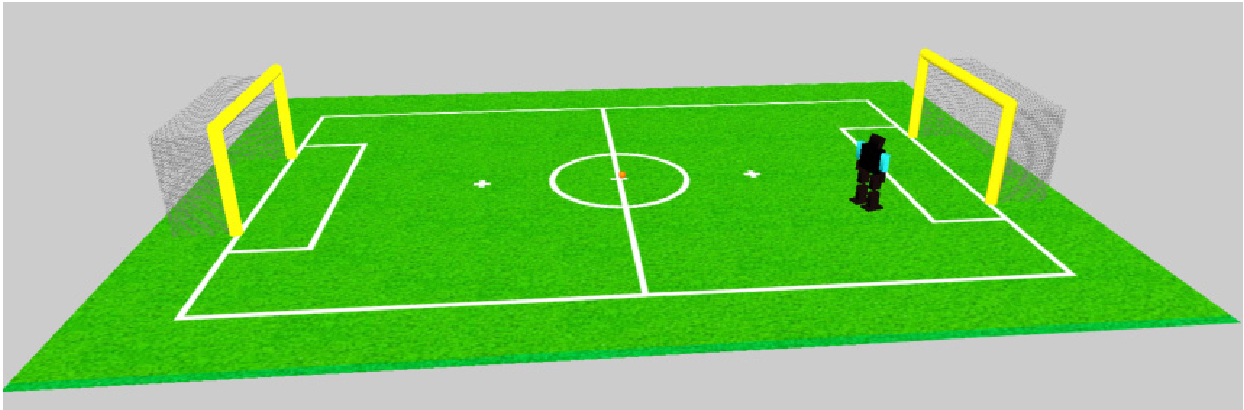

Fig. 2. Humanoid robot soccer field (aerial view)

2.2 Attack and Defense

Not more than one robot of each team should be inside the goal or the goal area at any time. If more than one robot of the defending team is inside its goal or goal area for more than10s, this will be considered illegal defense. If more than one robot of the attacking team is inside the opponent's goal or goal area for more than 10s, this will be considered illegal attack.

2.3 The Penalty Kick

(1) A goal may be scored directly from a penalty kick.

(2) The player taking the penalty kick is placed at a distance of at least 1.5H from the penalty mark.

(3) The defending goalkeeper is placed in upright position on the middle of his goal line, facing the kicker. It must remain upright between the goalposts until the ball has been touched by the kicker.

(4) No other players are allowed on the field.

(5) When both players are ready, the ball is placed randomly within 20cm of the penalty mark.

(6) After the referee gives the start signal, the striker has 60s to kick the ball once or multiple times. After this time, the trial ends if the movement of the ball obviously does not result in a goal. Otherwise, the trial is extended until the ball stops.

2.4 Advantages of Lobbing

In humanoid robot soccer, the penalty situations often encountered are shown in the Fig. 3. At this time, the high ball can cross the defensive robot with a height of less than 50cm, squatting, sitting, lying on one side and falling on the other side, so as to easily break and score goals.

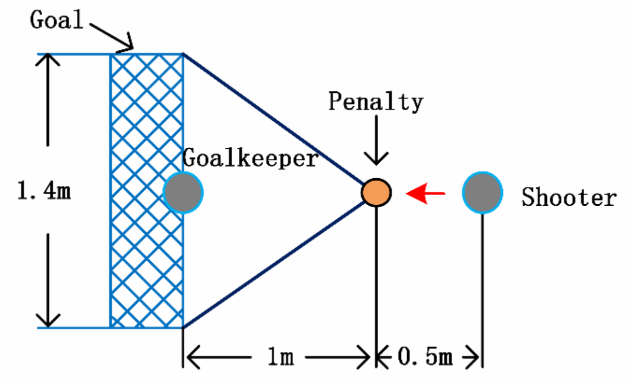

Fig. 3. Humanoid robot soccer shooting

3 Analysis of Kicking Action

Lobbing ball is a basic skill of football. It can be seen at any time on the training ground of football match. Those gaping shots, long-distance straight hanging goal dead corner wonderful goals. For long distance lobbing ball, use the instep taut method to hit the ball, right instep or instep inside hit the ball inside. The short distance lobbing ball, the thigh big swing drives the calf, finally uses the arch of the foot vigorously to hit the ball. Straighten the instep, the body can be a little side, leg power hit the ball under the test. Use the instep inside to hit the ball directly below, the foot needs to be straight, the left supporting foot should be parallel to the ball, and the ball under the right foot should hit the ball just right. The body leans to the left, the center of gravity can be slightly backward, hit the lower part of the ball with the inside of the foot (beginners can use the inside of the forefoot), and there is about 45 degrees between the foot and the hit part. The left foot is level with the ball, and the right thigh swings to drive the calf. The thigh is a burst of strength, and the calf also controls the ball's strength. The ankle and instep are taut. Don't relax before hitting the ball. Hit the ball hard. The techniques are as follows:

(1) Lock ankles and break toes back towards calves. We mentioned the importance of locking the ankle yesterday. The range of action of the ejection is very small, but it needs some strength. Therefore, the movement of feet must be standardized.

(2) Select the bottom of the kick.

(3) The knee drives the calf to pick the ball.

(4) The range of action with the ball after the shooting must be small.

3.1 Human's Lobbing

There are many kinds of human kicking actions, this paper mainly studies the forward foot kick. Kicking the ball on the back of the foot can be divided into two steps: back swing and front swing, as shown in Fig. 4. In the whole process, the batting leg swings backward first, and then swings to the batting sphere at high speed like a whip. When the back of the foot touches the ball, it drives the ball to move upward for a certain distance and then stops. The ball will continue to move due to inertia and form a parabolic trajectory in the air. Due to the need to maintain the dynamic balance of the body when kicking, the arm in the same direction as the batting leg will swing backward, and the arm in the opposite direction will stretch forward.

Fig. 4. Decomposition of human kicking action

By controlling the ankle to change the angle between the back of the foot and the calf, and controlling the lifting height of the foot, the rough control of the height and trajectory of the ball can be realized. Some trained professional football players can even achieve accurate control of the ball trajectory and landing point.

3.2 The Lobbing of Humanoid Robot

The appearance of humanoid robot is like human, and it can act like human, so humanoid robot can imitate human's kicking action. The humanoid robot's high kick can be divided into two steps: back swing and front swing.

Take the right leg stroke as an example, as shown in Fig. 5. In the standing state, the robot first retracts the right leg backward, and slightly tilts its body like the left front to maintain stability. Then lift the knee forward, while the right arm begins to swing back and the left arm begins to extend forward to maintain balance. Finally, kick the right leg forward, buckle the toe of the right foot slightly, swing the right arm backward, extend the left arm forward, and tilt the body slightly like the left rear to maintain balance.

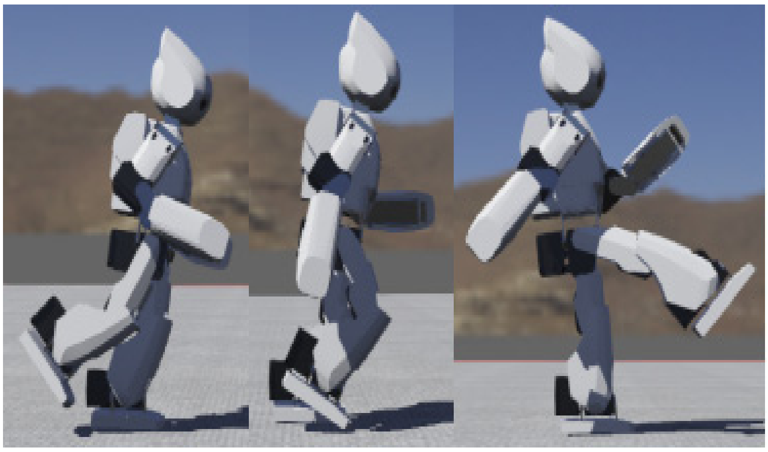

Fig. 5. Humanoid robot imitates human forward foot kick

The speed and trajectory of the kick are related to the kick speed of the kick leg, the height of the toe and the angle of the toe to the calf.

In some simulation games, the kicking action of the robot is shown in Fig. 6. After the robot kicks out the right foot, the body falls backward, and at the same time, arms swing back to contact the ground. At this time, both arms and left leg are used as support to ensure the stability of the robot after lobbing ball. As the body is tilted back greatly, the right foot has higher kicking height and speed.

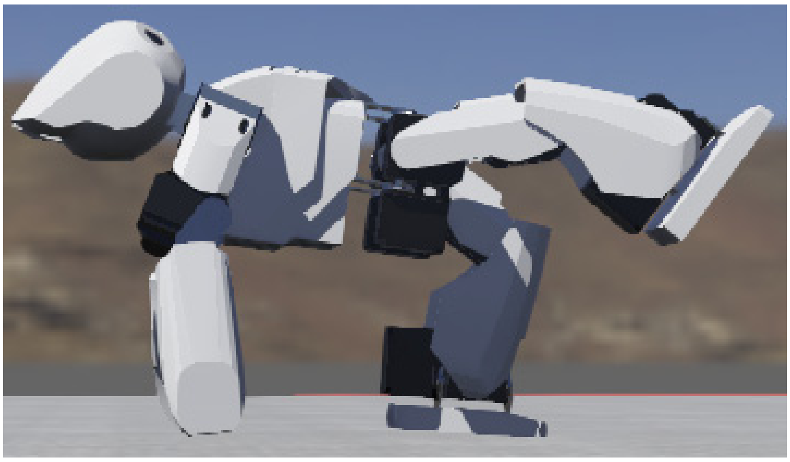

Fig. 6. Theoretical optimal kicking action

The advantage of this action is that it can make the kick higher and faster. The disadvantage is that at the moment when the body falls back, the double arm steering gear and the steering gear at the knee of the supporting leg are subjected to great impulse, which requires high steering gear. Therefore, it is not practical in the real robot, but it is widely used in the simulation games as a kicking animation.

3.3 Human Motion Capture Data

Human motion analysis [7-10] is to obtain human motion information from video, analyze, identify and use it. The basic idea of motion capture for complex motion design of humanoid robot is that using human motion posture is the combination characteristics of different spatial angles between adjacent limbs. Chen [11] analyzed the Acrobot model of under actuated horizontal bar robot. According to the technical requirements of IHOG, the body structure and degree of freedom configuration of physical robot, the motion control strategy of humanoid robot horizontal bar based on HMCD is proposed. The motion data of human horizontal bar is analyzed through video, and the key feature points are analyzed according to the humanoid robot model. The joint angle data of key frames obtained from the motion data of basic actions are adjusted by appropriate kinematic constraints. Based on the 3Dmax simulation environment, the motion trajectory of humanoid robot is generated by interpolation method.

4 Action Principle Based on Darwin-op2

Darwin-op2 robot is a humanoid robot produced by robotic company of South Korea. The Darwin-op2 robot can use to play a cooperative game of concentration with a human [12]. It weighs 2.9kg and is 45.45cm high. It has 20 mx-28 digital steering gears, including 6 arms, 12 legs and feet, and 2 head and neck, as shown in Fig. 7.

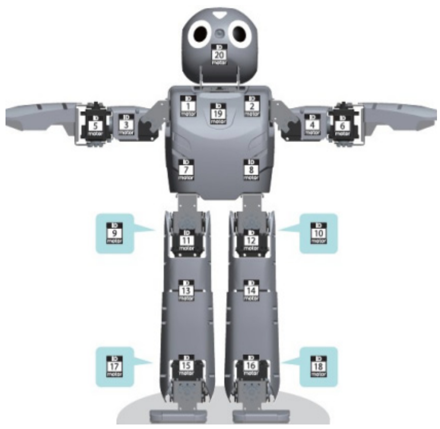

Fig. 7. Schematic diagram of steering gear of darwin-op2 robot

The hardware specifications are shown in Table 2.

Table 2. The darwin-op2 parameter

Hardware	Specifications
CPU	Intel Atom N2600 @1.6GHz dual core
RAM	up to 4GB DDR3 204-pin SO-DIMM module (user-replaceable)
Storage	half-size mSATA module (32GB) (user-replaceable)
LAN speed	1 Gbps
Installable OS	any Linux release (32-bit) any Windows release (32-bit)
wi-fi	802.11n (2.4GHz-only)

4.1 Restricted Conditions of Darwin-op2

When using darwin-op2 robot in football competition, there are two objective factors that restrict its performance of lobbing ball, namely, the strength of mx-28 steering gear, the diameter and weight of the ball kicked.

The single leg weight m of darwin-op2 is about 0.5kg, and the distance L from the leg steering gear to the sole of the foot is about 0.2 m when standing. Note that the angular velocity in the process of kicking is ω, the time taken is t, and the leg lifting angle is θ. The model is shown in Fig. 8.

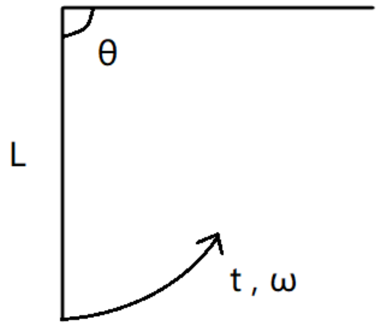

Fig. 8. Darwin-op2 model

In the process of darwin-op2 lobbing ball, the torque of the upper steering gear (ID = 11, 12 in Fig. 4) in the batting leg is the largest. The moment acting on the upper steering gear of kicking leg can be calculated by formula (1).

$$M = J\beta \tag{1}$$

Where J is the moment of inertia of the batting leg and β is the angular acceleration of the batting leg.

The knee steering gear (ID = 13, 14 in Fig. 5) in the support leg bears the largest moment (bearing almost the whole body weight). The moment M of supporting leg can be calculated by formula (2).

$$M = L \cdot mg \cdot \sin\alpha \tag{2}$$

Where L is the length of the robot's thigh, M is the residual mass of the robot after removing the leg and foot, and a is the angle between the leg and the vertical direction.

When the kicking speed is too fast, the gear on the upper rudder of the batting leg is worn. At the same time, the robot can't maintain the kicking posture for a long time due to the excessive torque on the knee actuator of the supporting leg. Therefore, in the design of the action, we slightly reduce the angular velocity α and the leg raising angle θ and release the force of the whole body steering gear after kicking the ball, so as to ensure the safety of the steering gear when the robot kicks the ball.

From the point of view of the ball, its weight will affect the torque of the supporting leg steering gear, and its diameter will affect the hitting surface of the robot, thus affecting its own trajectory. The maximum height of the sphere is

$$h_{\max} = h + v_0 \cos\theta (1 + \frac{v_0 \cos\theta}{2g}) \tag{3}$$

Where h is the initial height of the ball, v_0 is the initial velocity of the ball, and θ is the angle between the initial velocity and the vertical direction.

5 Action Decomposition of Darwin-op2

5.1 Accent in Movement

According to the analysis of humanoid robot lobbing ball in 2.2, we divide the action of darwin-op2 robot into two steps: back swing and front swing. Due to the strength limitation of mx-28 digital steering gear, we slightly reduce the leg lifting angle and limit the kick speed to a safe range. The main actions are shown in Fig. 9.

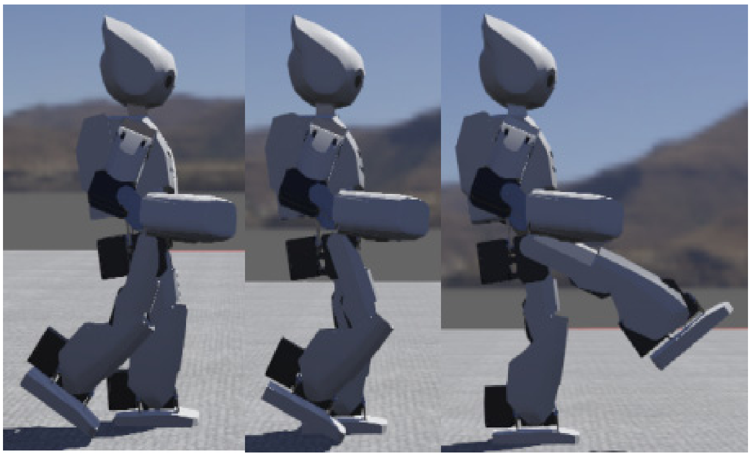

Fig. 9. Main action of darwin-op2 lobbing ball

5.2 Increase Kick Height

In order to compensate for the reduced leg lifting angle due to the limitation of steering gear, we make the body of darwin-op2 robot lean back slightly, and increase its lifting height indirectly while keeping the lifting angle of batting leg unchanged. The comparison of leg lifting height is shown in Fig. 10.

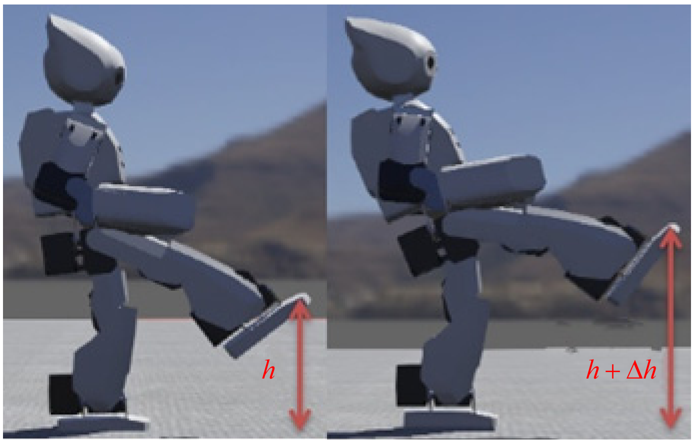

Fig. 10. Comparison of leg raising height between non reclining (left) and reclining (right)

The increased lifting height Δh can be obtained from formula (4).

$$\Delta h = [\cos\theta - \cos(\theta + \Delta\theta)] \cdot L \quad \textbf{(4)}$$

Where θ is the lifting angle of the batting leg relative to the upper body extension line, $\Delta\theta$ is the back swing angle of the supporting leg relative to the upper body extension line, and L is the leg length of the robot.

Obviously, the kicking height can also be increased by changing the shape of robot feet. Because the toe height of darwin-op2 robot is 0.8cm and the hitting point is high, the horizontal component of the ball motion is larger than the vertical component. According to formula (3), the maximum height of the sphere is obviously limited. In order to solve the problem that the hitting point is too high, we redesigned the foot plate shape of darwin-op2 on the premise of abiding by the rules of all kinds of humanoid robot football competitions, and designed the toe of darwin-op2 as a wedge shape, as shown in Fig. 11.

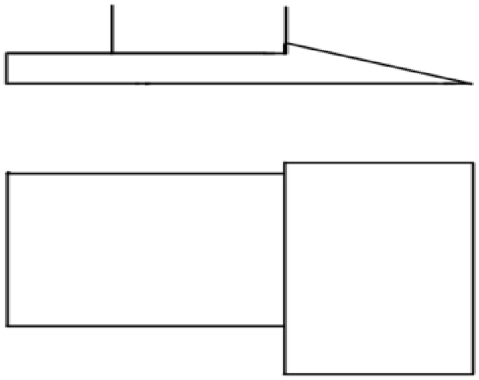

Fig. 11. Side view (top) and top view (bottom) of wedge foot plate

The foot structure greatly reduces the height of the hitting point, makes the vertical component of the ball motion greater than the horizontal component, and greatly improves the maximum height of the ball motion.

5.3 Solve the Problem of Physical Stability

Although the above action has achieved the high kick, there is the problem that the body is not stable in the process of kicking and the side falls to the hitting leg. We add the arm swing action of human kicking to the kicking action of darwin-op2, and slightly tilt the robot's body to the left and back to ensure the dynamic balance in the process of kicking. The action is shown in Fig. 12.

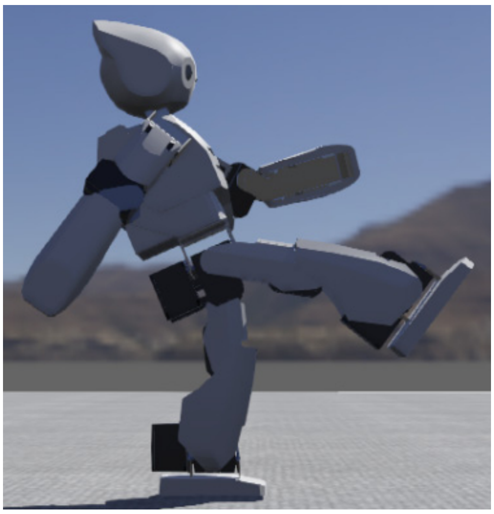

Fig. 12. Kicking with arm swing and center of gravity adjustment

6 Conclusion

At present, there are two kinds of humanoid robot soccer balls, which are small ball with diameter of 6cm and mass of 18.2g and big ball with diameter of 9.5cm and mass of 44.8g. Here we use the small one. The ball is shown in Fig. 13.

Fig. 13. The small ball

6.1 Ideal Experimental Data

We ignore the process of the robot looking for the football and approaching the football. Under the ideal condition that the robot must be able to kick the football, we test the ball 100 times and record the maximum height of the ball. The ideal test is shown in Fig. 14.

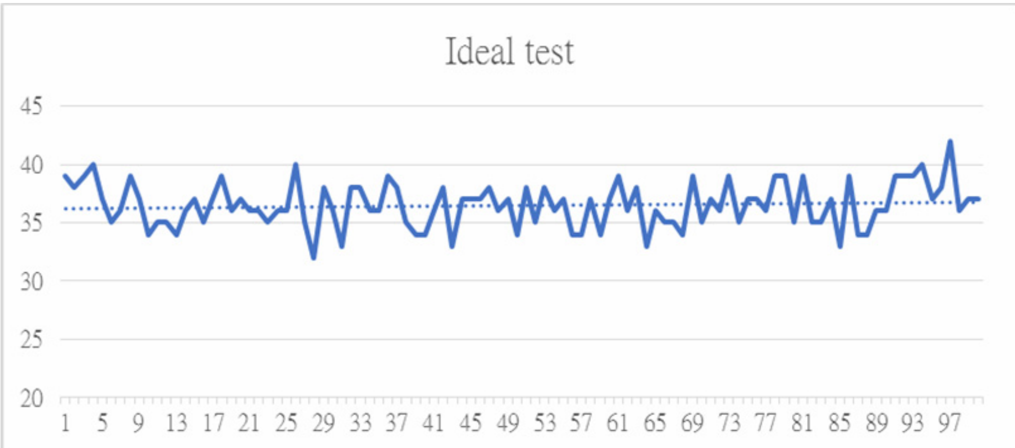

Fig. 14. Test line chart of small ball under ideal condition

6.2 Experimental Data in Actual Situation

We put the high kick into the main program to let the robot search, approach and fly the football independently. In this case, the ball was tested 100 times and its height was recorded. The actual test is shown in Fig. 15.

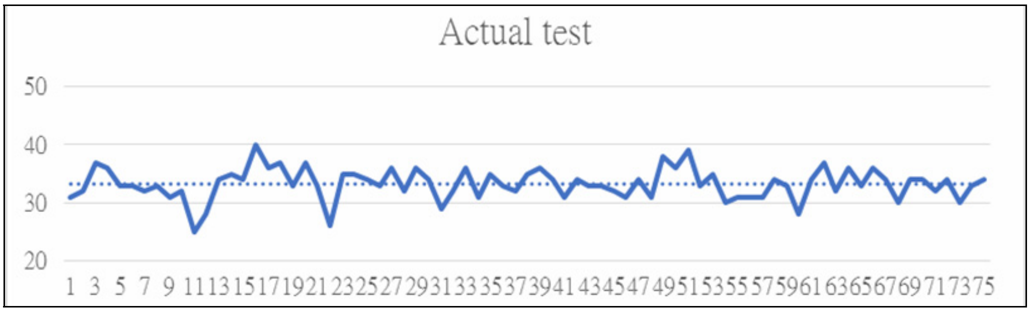

Fig. 15. Broken line chart of ball test in actual combat

6.3 Result Analysis

We calculate the average value, maximum value, minimum value and variance of the three groups of experimental data, and calculate the success rate of lobbing ball in actual combat, which is summarized in the Table 3.

Table 3. The result analysis

	Actual test	Ideal test
Average height	33.3	36.51
Maximum	40	42
Minimum value	25	32
Variance	7.17	3.67
Success rate	75%	100%

At present, in humanoid robot soccer competition, the goal keeping actions of robots mainly include upright, squatting, sitting, lying on the side, leaning on the side and so on. According to the test, the 45.45cm-tall darwin-op2 robot can lob ball over the defense robot with the height below 50cm, which is squatting, sitting, lying on the side and falling on the side, while the upright defense robot can break the defense by using the dead corner ground roll due to the limited left and right width.

In the ideal situation, the factors that affect the height of the robot kick are the position error of the artificial ball, and the height and angle error caused by the robot's own balance. In the actual combat situation, the factors that affect the height and success rate of robot kicking include not only the above two points, but also the image recognition algorithm error and the position error of robot stopping in front of the ball. The algorithm error and position error can be solved by optimizing the algorithm and adjusting the parameters.

7 Discussion

In order to solve the problem that humanoid robot soccer competition is generally two-dimensional competition, and Robot Attack and defense tactics tend to be single, which leads to the lack of competitiveness and appreciation, this paper analyzes the human foot back kick action, and designs a complete set of high kick action based on darwin-op2 robot innovatively, which improves the competitiveness from two-dimensional to three-dimensional, It also provides a new direction for the development of humanoid robot soccer in the future. At the same time, due to the limitation of mx-28 digital actuator strength, darwin-op2 robot does not play the optimal performance of this set of actions. If the steering gear with higher strength can be used, the current kicking action can be further optimized to achieve the theoretical optimal action shown in Fig. 4, and even make a similar "upside down golden hook" action in human football competition.

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