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Retraction

Retracted: Application of Neural Network in the Stability of Biped Robot and Embedded Control of Walking Mode

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Journal of Electrical and Computer Engineering has retracted the article titled "Application of Neural Network in the Stability of Biped Robot and Embedded Control of Walking Mode" [1] due to concerns that the peer review process has been compromised.

Following an investigation conducted by the Hindawi Research Integrity team [2], significant concerns were identified with the peer reviewers assigned to this article; the investigation has concluded that the peer review process was compromised. We therefore can no longer trust the peer review process, and the article is being retracted with the agreement of the editorial board.

References

[1] J. Zhang, Z. Yuan, H. Geng, S. Dong, F. Zhang, and J. Li, "Application of Neural Network in the Stability of Biped Robot and Embedded Control of Walking Mode," *Journal of Electrical and Computer Engineering*, vol. 2022, Article ID 7474820, 10 pages, 2022.

[2] L. Ferguson, "Advancing Research Integrity Collaboratively and with Vigour," 2022, https://www.hindawi.com/post/advancing-research-integrity-collaboratively-and-vigour/.

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Research Article

Application of Neural Network in the Stability of Biped Robot and Embedded Control of Walking Mode

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The biped robot adopts the human movement mode. Compared with other movement modes, the gait has good flexibility and adaptability. It is very important in the research of robotics, so it has become a hot spot of robotics research. This article aims to study the application of neural networks in the stability of biped robots and the embedded control of walking mode. A method of establishing precise mathematical modeling and stability analysis is proposed. Based on this model, the motion characteristics of the biped robot's walking mode and the local stability of joints are studied, and the motion mode of passive walking under the control of the neural network is deeply analyzed, using a neural network to control the stability of biped robot motion and adopting the research method of the embedded control system in walking mode. Essentially, the output value of the physical network is used to judge whether the robot is in a stable position so as to perform appropriate actions and control the robot's stability of walking. The experimental results show that the biped robot can detect movement and overcome obstacles through related networks and embedded control systems. Through the control of the embedded system, the errors of each joint of the biped robot on flat ground, stairs, and obstacles are greatly reduced. The most obvious reduction of the deviation is that the ankle joint decreases from 2.5 to 0.07 when rotating, and the knee joint angle deviation is reduced from 3.8 to 2, which greatly improves the stability of the biped robot's walking mode.

1. Introduction

At present, the research level of biped robots in foreign countries is much higher than that in China, and the gait planning of biped robots in China is mostly limited to timing planning and interpolation of joint parameters [1]. The research has limitations and is not deep enough and is based on the inverted pendulum planning method. In research, most researchers rely too much on the physical hardware platform of the biped robot. The theoretical research process of the analysis and synthesis of the dynamic biped robot control system is relatively lagging behind the development of the prototype, and most of the research on stability is only limited to the display of movement patterns; it lacks further analysis of walking gait or comparison and optimization with other planning methods.

The biped robot has a structure similar to a human body, and its motion mode is similar to that of human walking [2]. It includes mechanical structure, driving mode, sensors, information communication, and operating actions is a comprehensive scientific and technological product. Tasks that are difficult to complete have indispensable research value. Unlike traditional wheeled robots, crawler robots, etc., which have relatively stable motion support, biped robots do not have relatively stable support points when they move, so walking stability has always been a difficult issue to consider for biped robots, especially for running and in complex motion environments such as up and down the stairs, the motion stability of biped robots is particularly important.

Due to the very complex characteristics of the robot system, there are not many tools that can be effectively applied to the design and analysis of the robot system [3].

Although the research on robot system control is complex and challenging, many scholars at home and abroad still face difficulties and devote themselves to research in this area. Jaramillo-Avila explored the aspect of robotic programming. He first started from the neuromorphic aspect in this aspect. He believed that neuromorphic engineering is a rapidly developing research field, and its main goal is the biologically inspired design of hybrid hardware systems to imitate neural architecture and process information in the manner of the brain. The main goal of this work is to show how such applications work properly by creating closed-loop systems using only bionic technology [4]. Baoling uses a robot as an agent to train to walk stably on uneven surfaces with obstacles, using a simple reward function based on forward progress. The reward and punishment (RP) mechanism of the DQN algorithm is a pregenerated foot trajectory plan established after the offline gait is obtained. The proposed method is not to implement a complex dynamic model but to make the biped robot learn to adjust its posture on uneven ground and ensure walking stability [5]. Huan research on biped robots mentioned that inverse kinematics is derived for the specified positions of the hips and feet. The goal is to optimize the biped robot so that it can walk stably and naturally with a preset foot lift (or a preset hip shift or a preset step length). The stability of the biped robot is quantified by the distance between the ZMP and the center of the foot in the step cycle, which represents the first objective function. In addition, for the biped robot following the preset foot-lifting value, the difference between the foot-lifting value and the preset foot-lifting value represents the second objective function. Specifically, we minimize the values of the two objective functions by treating the gait parameters of the biped robot as variables. Innovatively, we apply the new Jaya optimization algorithm to optimize the gait parameters of the biped robot to ensure the stable and stable walking of the biped robot [6]. However, most of the above methods are based on the known robot system. Their research is mainly aimed at the basics of biped robot walking and the gait control of robot walking in the passive state. This enriches the case study in the field of biped robots, reference, and practical value. However, the current research on biped robots involves a higher level, and their research is limited to basic research. In order to bring greater value, multifaceted and multi-technical considerations are required.

In order to enable the biped robot to obtain a high-speed, efficient, and stable dynamic walking gait, this article is based on the stability study of the biped robot during the walking process and mainly analyzes the stability of the neural network in the biped robot and the embedded control strategy [7]. The design was studied. This research combines the neural network and embedded control mode to achieve the goal of controlling the biped robot to walk smoothly on various complex grounds. This will bring important research and practical value to the robotics application industry. By consulting related literature on the structure, kinematics model, and gait planning of the biped robot, the dynamic stability of the biped robot is analyzed and researched with the help of a neural network and embedded control mode, and the embedded control system is constructed. Software and hardware platform are embedded control systems [8].

2. Basic Theoretical Knowledge

2.1. Embedded Control of Biped Robot Walking Mode. The robot control system includes two main modules [9]: module and software module. In terms of application modules, with the advanced development of embedded computer functions, its advantages such as small size, low cost, and strong compatibility with the enterprise control field have emerged, and more and more robot control systems around embedded controllers have become the mainstream [10]. Artificial neural network solves many problems that cannot be solved by traditional information systems by virtue of their intelligent characteristics and robust performance and has developed into an important branch of intelligent management [11]. With the development of embedded technology, the cost of applied materials has dropped, and the performance of embedded systems has increased rapidly. Embedded systems provide a support platform for more and more complex information management capabilities. A physical network with highly offline mapping, self-organization, personal learning, connected memory, and other functions, can model complex loopholes in the stability of biped robots, and can achieve satisfactory control results by virtue of mathematical models or systems with calculation models. Embedded control has the characteristics of fast response speed, strong anti-interference ability, simple algorithm, and flexible interaction with machines and software [12]. In the dynamic voltage signal data acquisition, the maximum change rate of the signal is 0.1 V/ms. When only the error factor of the acquisition control lag is considered, if the given error of the signal voltage should be 1 mV, it can be roughly estimated to meet the actual requirements. The response time t_a of the training data acquisition task is required, $t_a = 1\ \text{mV}/(100\ \text{mV}/1\ \text{ms}) = 0.01\ \text{ms}$. If the data acquisition time consumption of the system t_s can meet the requirement of $t_s \leq t_a$, the embedded control system can realize real-time data acquisition.

With the development of electronic technology, embedded systems have become more and more powerful [13]. They can not only consider the functions of device management and general networking but also integrate the functions of a network server. It mainly includes two aspects, namely, material efficiency and technical feasibility. With the rapid development of computer network technology, network technology has been widely used in life and work, and the application of technology-embedded network products has broad growth expectations. Analyzing the connection between embedded technology and Ethernet technology will surely promote the development of remote control of embedded devices [14]. The installation system is small in size, is low in cost, is easy to install and use, and has low environmental requirements. Replacing computers with embedded systems in the monitoring of multiple sensors and control equipment and the development of intelligence, networks, and universal wireless controllers is an important research in the development of network control systems. The development and research of embedded Linux is a hot topic in the field of systems [15, 16].

2.2. Kinematics Model of Biped Robot. The link motion of each part of the biped robot can be similar to the motion of a rigid body, so the method of describing the motion of the rigid body can be applied to the motion of each joint of the biped robot [3]. The homogeneous transformation method is widely used to describe the kinematics of robots because of its advantages that other methods do not have. Based on the homogeneous transformation method, the kinematics of the biped robot is further developed. Modeling and rotating coordinates lay the foundation for the next step of gait setting [17]. Therefore, this experiment adopted this method to construct the kinematic model of the biped robot. Through the analysis of the joints of the biped robot, it can be known that the biped robot mainly uses rotating joints in the movement process. Therefore, we mainly analyze the rotation coordinate transformation related to the rotating joint. Assuming that the left hip joint of the biped robot is the Q point, the motion exists in space, so the position $Q(x_{0,}y_0, z_0)$ of the Q point can be represented by three-dimensional coordinates, according to the point Q in the local the position change of the coordinate system (o, m, n) before and after the rotation can be obtained [18]:

$$\begin{bmatrix} Q_x \\ Q_y \\ Q_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} Q_o \\ Q_m \\ Q_n \end{bmatrix}. \tag{1}$$

The kinematic model of point P is constructed by the homogeneous transformation method and the coordinate system is set to W [19]:

$$\begin{gathered} {}^a_bW = [{}^ax_b, {}^ay_b, {}^az_b] \\ (x_a, y_a, z_a) = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}. \end{gathered} \tag{2}$$

As can be seen from the above figure, the matrix coordinates of ${}^a_bW$ include nine factors, among which are three independent elements on the three coordinate axes [20]. The corresponding rotation matrix of the x-axis rotation angle α can be obtained according to formula (1):

$$W(x, \alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix}. \tag{3}$$

Similarly, around the y-axis and z-axis, the corresponding rotation coordinates can be obtained, respectively.

In addition to the rotation of the joints during the movement of the biped robot, there is also a state of limb swing [21]. It is assumed that there is no relative sliding between the supporting leg of the biped robot and the ground during the swing phase of the single-leg support. The Lagrange equation is used to derive the dynamic equation of the robot in the swing phase as follows:

$$\begin{gathered} L(\eta)\dot{\eta} + I(\eta, \dot{\eta})\dot{\eta} + H(\eta) = S_v, \\ {}^0L_t = {}^0L_1{}^1L_2 \ldots {}^{O=1}L_O = \left[{}^0q_o^0l_o01\right]. \end{gathered} \tag{4}$$

η is the angle between the supporting leg of the biped robot and the swinging leg, $v = [v_1, v_2]^t$ is the driving torque, and v_1, v_2 are the torque applied at the hip joint and ankle joint of the supporting leg. If the biped robot is standing still or lying on its back, then $v = [0, 0]^t$ [22].

The momentum theorem is a theorem with obvious physical meaning derived from Newton's differential equations of motion:

$$\begin{aligned} w &= w \cdot k, \\ L_0 &= -J_{xz}w \cdot i - J_{yz}w \cdot j + J_z w \cdot k, \\ \frac{dL_0}{dt} &= w \times L_0 = J_{yz}w^2 \cdot i - J_{xz}w^2 \cdot j, \\ J_{yz}w^2 &= \sum m_x(F_i) - N_y'l. \end{aligned} \tag{5}$$

The perceptron neural network can control the action trajectory, movement speed, and mode of the biped robot and judge whether the robot is in a stable state through the output value of the neural network so as to perform corresponding actions to ensure the stability of the robot's walking [23, 24]. We think of a neural network as an impulse model for manipulating the operation of a biped robot. When the sensor sends instructions to the biped robot, the state under the internal drive force can be recorded as follows:

$$\begin{cases} q = d(q) + k(\dot{q})v, \ (q \notin w)0, \\ q_d = \gamma\left(q^d\right) - v_q, \ (q \in w)1. \end{cases} \tag{6}$$

The motion trajectory of point Q is determined by (q_d, q_v) in the above formula, 0 represents the initial value of the internal driving of the biped robot receiving the signal, and 1 represents the force of the internal driving force to promote the action [25]. The factors that affect the pulse model are as follows. (1) Magnet demagnetization: the magnet in the sensor will demagnetize as time goes on so that the sensor cannot output the pulse signal. (2) Magnetic field interference: the pulse signal is subjected to electromagnetic interference during the transmission process, resulting in errors. (3) Mechanical vibration: the robot itself is affected by external vibration, which will cause the pulse sensor to send out abnormal pulse signals, resulting in pulse errors.

When considering the neural network to control the motion of the biped robot, the propagation speed of the medium ultrasonic wave needs to be studied, and the calculation result from the sending instruction to the receiving signal is as follows:

$$\begin{aligned} L &= r \cdot \frac{T_{tof}}{2}\frac{\lambda}{t}, \\ r &= T_{r-1}\left(\frac{{}^cr}{3} \pm 2\gamma \cdot \sqrt{c}\right)\begin{pmatrix} \le 1 \\ > 1 \end{pmatrix}. \end{aligned} \tag{7}$$

T_{tof} is the time to monitor the propagation process, T is the temperature during the propagation of the medium, r is the ultrasonic wave, and the ultrasonic wave $r = 331.4\sqrt{1 + t/273}\text{mps}$.

As long as the time from the transmission of the ultrasonic signal to the reception of the echo signal is calculated and the propagation speed of the ultrasonic wave in the medium is known, the distance to the measured object can be calculated:

$$d = \frac{s}{2} = \frac{vt}{2}. \tag{8}$$

Among them, d is the distance between the object to be measured and the robot, s is the round-trip distance of the ultrasonic wave, v is the propagation speed of the ultrasonic wave in the medium, and t is the time it takes for the ultrasonic wave to transmit to the reception.

2.3. Stability of Biped Robot. Biped robots have broad application prospects and high practical value and have been widely concerned by researchers. However, due to their poor motion performance, which is specifically reflected in the low speed and high energy consumption, biped robots are still in the early stages of development and there is still a lot of room for development. The walking of a biped robot can also be regarded as the regular contact movement between the feet and the ground, that is, the periodic movement from the support of the legs to the alternate support and swing of each leg.

According to the principle of stability, we can get the following:

$$\phi_{\min}\|a\|^2 \le a^{\alpha} X \le \phi_{\max}\|a\|^2. \tag{9}$$

In formula (9), $\phi_{\min,}\phi_{\max}$ represents the minimum eigenvalue and maximum eigenvalue of X, and $\|a\|$ represents the Euclidean norm.

In order to observe the stability of the biped robot's motion process more intuitively, we use fitted linear parameters to study it to ensure the reliability of the experiment and improve the authenticity of the experimental data. The calculation method of the fitted linear parameter is as follows:

$$\begin{aligned} p_i &= u_i \cdot X_t^{i-1}(i) + \varpi_i(A), \\ X_t^{i-1} &= \operatorname{argmin}\left|p_i(A) - Xm_i(A)\right|. \end{aligned} \tag{10}$$

Among them, X_t^{i-1} is an ideal known vector, and $\varpi_i(a)$ is the error in the process of fitting the motion of the biped robot. The ideal weight vector X_t^{i-1} is a robot value that is set according to needs through analysis. $m_i(A)$ is the embedded value of the neural network, and the formula combined with the ideal vector is as follows:

$$m_i(A) = \text{cxe}\left[\frac{-(A-\delta_i)^t(a-\delta_i)}{\delta_i^2}\right]. \tag{11}$$

When the biped robot walks, its two feet are in contact with the ground from time to time, and the ground supporting surface is constantly moving, changing with the walking motion. If the predicted point of the center of gravity of the robot on the ground can always fall within the support point during walking, then it is said that the biped robot is entering a stable position. Because the biped robot is in the process of walking, the one-foot support is most prone to fall. According to the COG principle of the ground projection point of the center of gravity, the position of the projection point under the condition of single foot support is as follows:

$$W_{cog} = \sum_{a=1}^{i}\left(t \pm \frac{1}{a^2(a-1)} \cdot \alpha\right). \tag{12}$$

According to the ground projection point of the center of gravity, the stable motion of the biped robot can be ensured through geometric constraints so that the trajectory of the joint motion of the robot can be obtained.

3. Design of the Experiment

3.1. Research Object

(1) The dynamic biped robot represented by compass-like: this research is based on the perspective of the neural network, and compass-like is the research basis of completely passive walking and semipassive walking—a pivotal position.
(2) The dynamic biped robot represented by ROBOT-1: ROBOT-1 is similar to a life-size robot and has a motion control system, visual system, and auditory system. At the same time, ROBOT-1 also has a manipulator with tactile sensors.

3.2. Research Method

(1) Perform physical modeling of the single-leg support and dual-leg support dynamic modes, and conduct stability analysis based on the kinematic model that is easy to control.
(2) Calculate and record the motion trajectory of each joint according to the kinematics algorithm, confirming the effect of the embedded control system on the stability application of the biped robot.
(3) The factors that affect the walking stability of the biped robot are analyzed, and the errors of each joint that can reflect the dynamic stability of the robot before and after the neural network control are used to obtain the conditions for strengthening the walking stability.
(4) Path planning requirements, detailed analysis of the hardware design of the control system, and feasibility demonstration of functional modules such as sensors, neural networks, and embedded systems are examined.
(5) An online walking pattern generation method for predictive control of the dynamic trajectory of a biped robot is proposed, which overcomes the

performance degradation of predictive control in the case of model mismatch caused by environmental disturbances, and enhances the adaptability of biped walking.

3.3. Experimental Results

(1) When using the three-dimensional coordinate method to model the biped robot, analyze the walking mode of the biped robot with reference to the structure and movement characteristics of the human lower limbs.

(2) The biped robot can walk smoothly and overcome obstacles through appropriate neural networks and embedded control methods.

4. Stability of Biped Robot

4.1. Predictive Control of Biped Robot's Stable Walking Mode. One of the biggest characteristics that a humanoid robot should have is walking. For biped walking robots, the stability of the walking mode is the main problem, and it is also the main problem faced by the current research on biped walking robots. It is the basis and prerequisite for other complex tasks. Because the center of gravity of the robot is high and the stability area is low, maintaining stability and balance is the simplest movement in walking but the most difficult control bottleneck. In the process of walking, people are affected by the joint action of skeletal muscle and nervous system so that people can walk stably at a certain speed. The movement boundary table of various parts of human lower limbs is attached, as shown in Table 1.

The above table is the best range of walking motion formed by long-term human evolution. Humans realize some common motions such as walking, running, climbing stairs, and jumping. The motion range of each joint degree of freedom is within the normal range, so humans walk daily. In the process, there will be no adverse phenomena such as mutual interference and the impact of various joints. Some test methods for measuring muscle signals test that the energy consumption of people during walking is very low. In order to simplify the workload of the experiment, it is assumed that the limbs of the biped robot are rigidly connected. Therefore, if a biped robot wants to reproduce some basic human gait, its range of motion must meet the above conditions, and considering the overall flexibility and stability of the robot and the noninterference phenomenon of each joint, the joint freedom of the biped robot is limited. The scope has changed from that of human beings; see Table 2.

The kinematics model of the biped humanoid robot analyzes the physical position of the robot during the transfer process through a mathematical model. There are two parts: one part is the known geometric calculation and the joint angle motion of the robot linkage model. The other part of the problem is the movement of important parts of the biped robot's body over time based on gait projection, and the solution of the angle of each joint of the robot is usually called the inverse kinematics problem. In order for a biped robot to walk on flat ground, climbing, downhill, etc., the biped robot must be able to move freely in three modes of limb swing, pitch, and rotation (Figure 1). Therefore, when modeling a biped robot, the center point of each joint of the lower limb of the robot is selected as the origin of the respective coordinate system, and the directions of the X, Y, and Z axes of each coordinate system are based on the construction method of the X, Y, and Z axes of the reference coordinate system. It is confirmed that an open-loop chain structure can be used to represent the posture of each link of the biped robot. Figure 2 shows the dynamic model of the biped robot.

In essence, the bipedal humanoid robot (Table 3 is the appearance composition coefficient of the compass-like bipedal robot, which is the research object of this study) is a nonlinear and unstable system. If it only relies on single limb support, it is fixed according to the regulations. The path and the existing stability and reliability of the design: the robot will eventually lose its balance, and the way the model itself creates the path depends on many assumptions; the type of model and the physical robot itself have errors. Therefore, it is necessary to combine sensors to detect the real-time information of the robot so as to understand the response control of the robot. The stability control of biped robots can be acheived through the combination of sensors and neural network.

4.2. Application of Neural Network in Biped Robot. Artificial intelligence neural network (see Figure 3 for the structure of the biped robot) has the following characteristics: nonlinear structure, parallel processing of multiple information, strong fault tolerance, adaptive adjustment rate, multiples data fusion technologies, and parallel and distributed processing, and it can update the system in real time through online learning method. Therefore, among many nonlinear controls, artificial intelligence neural networks have shown their strong vitality and application prospects.

The desired output of the neural network is generally determined according to the existing experience of manual adjustment and related experiments. A simulator that can simulate the self-learning of the neural network is used in advance to determine the weight of the network. These data do not need to be changed in subsequent experiments. This experiment determines the weights based on the dynamic mathematical model of the biped robot. Table 4 is the sample data table for this experiment.

If the value of each group of samples is used as the data of the neural network input layer, the quantized value of the motor simulation is the target value. Adding −1 to the input layer can introduce a threshold value for the hidden layer neurons, and the threshold value is merged into the weight value and adjusted with the algorithm, which simplifies the complexity of the calculation. The activation function of a neuron is a bounded function, in order to eliminate the influence of various factors due to different dimensions and units, prevent some neurons from reaching a

Table 1: Motion boundary table of various parts of human lower limbs.

Joint	Action direction	Action angle
Hip joint	Adduction	40°
	Abduction	45°
	Buckling	120°
	Extreme stretch	45°
	Rotation during flexion (appearance)	30°
	Rotation during buckling (internal view)	35°
Knee joint, ankle joint	Buckling	135°
	Adduction	45°
	Abduction	50°

Table 2: Motion boundary table of each part of the robot.

Movable joints of the lower extremities	Joint angle	Range of motion
Hip joint	$\theta 4$, $\theta 7$	−130° to 45°
	$\Theta 5$, $\theta 6$	−45° to −25°
Knee joint	$\Theta 3$, $\theta 8$	0°–150°
Ankle joint	$\Theta 2$, $\theta 9$	−50°–45°
	$\Theta 1$, $\theta 10$	−30°–40°

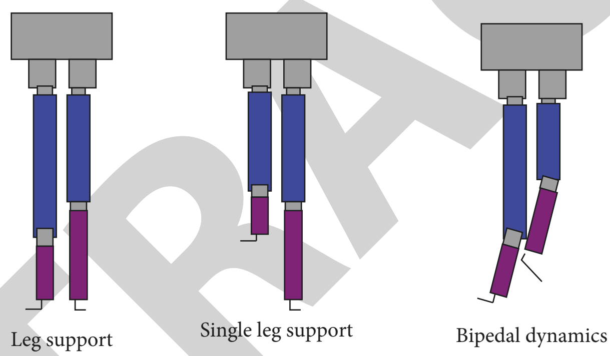

Figure 1: Abstract diagram of the dynamic mode of biped robot.

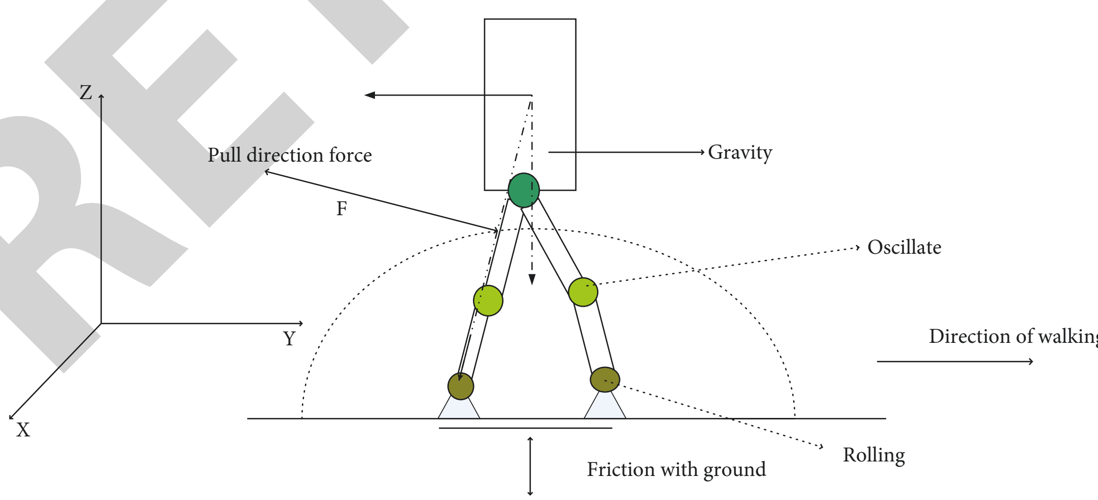

Figure 2: Biped robot walking model construction diagram.

supersaturated state, and at the same time make the larger input fall on the gradient of the neuron activation function. Therefore, the input vector and output vector are normalized before training and prediction. According to the dynamic space model of Descartes, we tested the stability of the biped robot under the control of the neural network under the dynamic state and obtained the experimental results in Figure 4.

Table 3: Compass-like biped robot lower limb member parameter table.

Component	Length (m)	Weight (kg)	Rod centroid
Right thigh	0.28	7.5	0.14
Right calf	0.28	4.5	0.14
Left thigh	0.28	7.5	0.14
Left calf	0.28	4.5	0.14
Torso	0.65	29.2	0.325

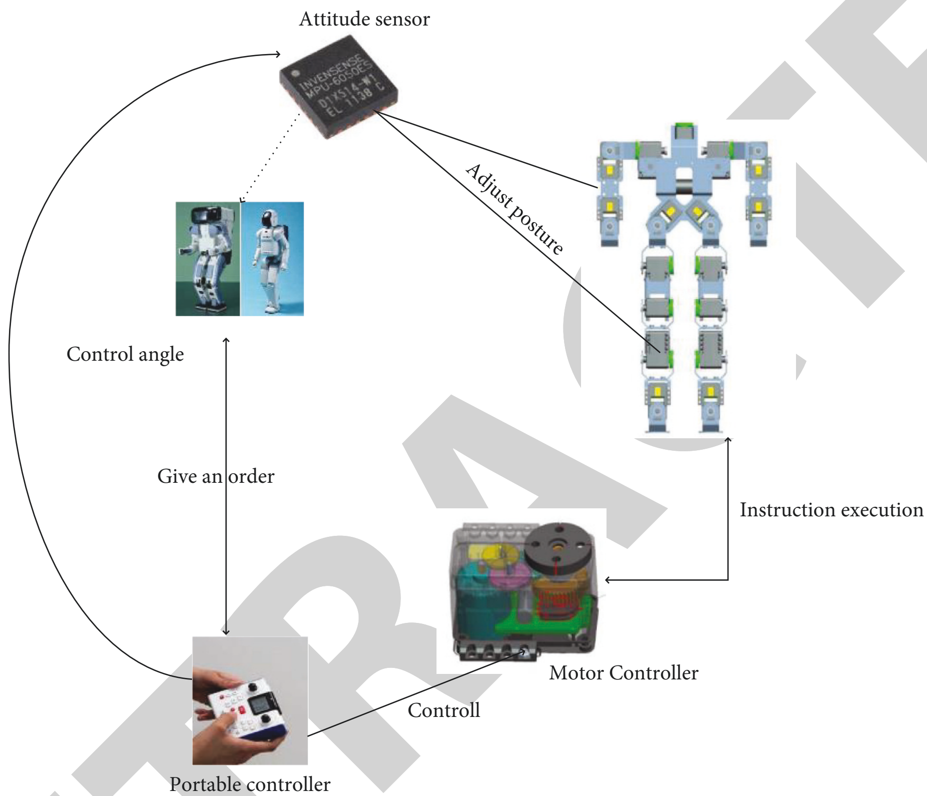

Figure 3: Structure of the biped robot.

Table 4: Network weight sample data table.

Sample	1	2	3	4	5	6
Motor analog value	1142.8	1257.6	1320.1	364.3	467.2	1078.3
Quantized value of motor analog	3.97	4.16	4.27	1.02	1.21	3.59
Neural network weights	4.89	5.93	6.01	1.47	1.79	4.41

The data in Figure 4 show that the neural network can monitor the dynamic trajectory of the biped robot very well, greatly increasing the stability of the biped robot's walking mode. Due to the nonlinear mapping ability of the neural network, neural network control is expected to directly obtain the stability control value of biped robot walking mode through parameter quantity. The given signal is input to the computer as the signal required for control. The computer detects the results of the neural network signal through the sensor. In the computer, the software algorithm is used for learning and neural network processing to generate control signals to control the power drive components so that the lower limbs of the biped robot can adjust the action with appropriate power.

4.3. Embedded Control of Walking Mode. Nonvisual sensors commonly used in robots include ultrasonic, infrared, and proximity sensors, which are used to perceive the proximity of objects in the environment to the robot. Through proper arrangement and combination of multiple sensors and data fusion of multiple sensors, the shape and size of objects in the environment can be obtained. When a voltage is applied to the ultrasonic sensor, its ultrasonic transducer is excited to emit ultrasonic waves in a pulsed manner, and then the ultrasonic transducer is transferred to the receiving state, the received ultrasonic pulse is analyzed, and the sound propagation process wave is measured. Embedded control is used to carry out the walking mode experiment of the biped robot. The first

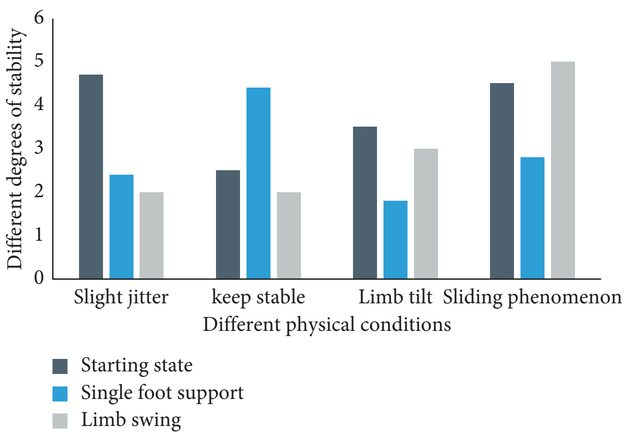

Figure 4: Simulation neural network control data for the walking mode of the biped robot.

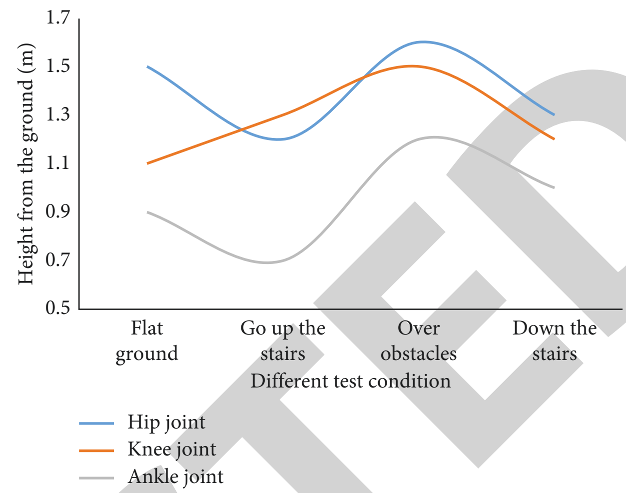

Figure 5: The trajectory of the biped robot in different situations.

item is gait planning; that is, the trajectory of the target point is given. Then the gait is derived from kinematics; that is, the trajectory of the joint angle changes with time; the item is to optimize the gait trajectory to judge whether the robot is stable. If it is unstable, modify the gait until it is stable; the third item is to control the robot in real time to ensure its stable walking.

In order to test the practical application of the embedded control system to the stability of the biped robot, the motion trajectories of each joint of the biped robot on the flat ground, up and down the stairs, and obstacles placed on the ground were simulated (Figure 5). Based on the planning method of the highest quality value, first, according to the position of the key point ankle joint during the walking of the biped robot, design a polynomial alignment to capture the motion path of the ankle joint, and then use the planned ZMP trajectory to use the optimal value method through the hip joint. Plan the route of the hip robot to get the moving gait of the biped robot during the whole walking process.

In order to verify the effectiveness of the embedded control, we compared the posture of the biped robot in this experiment and the errors before and after the rotation angle of the hip and ankle joints. The data before the experiment are recorded in Table 5, and the data after the experiment are recorded in Figure 6.

According to the analysis of embedded experimental data in Table 5 and Figure 6, when there is a large error, the biped robot will be out of balance when it swings or rotates greatly. Taking into account the overall flexibility and stability of the robot, the best way to adjust the torso without interference between the joints is to adjust the angle of the joints to support the torso and maintain stability. Calculate and record the motion trajectory of each joint according to the kinematic algorithm, confirming the effect of the embedded control system on the stability application of the biped robot.

Using the offline planning-online adjustment method, a plane walking experiment is carried out on the biped robot prototype built. The experimental results show that the biped robot can walk stably, and the compensation of the hip joint improves the stability margin of the ZMP, which also verifies the effectiveness of the walking method. The ground pressure data is collected in real time by the FSR pressure sensor arranged on the sole of the biped robot, and the trajectory of the actual ZMP and the expected ZMP is calculated as shown in Figure 7. It is found that the actual ZMP fits the expected ZMP position better, and the error between the two is kept within a manageable range.

Table 5: Statistics of each error value before the embedded control biped robot experiment.

Data category	Posture	Hip rotation angle	Ankle rotation
Max	0.21	1.2	3.8
Mean	0.07	0.46	1.02
Variance	0.004	0.16	1.17

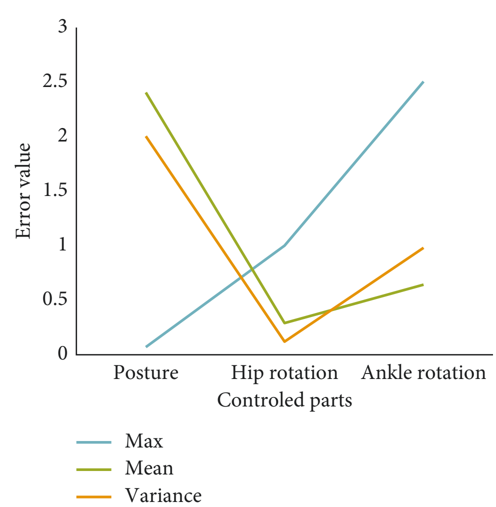

Figure 6: Statistics of each error value after the embedded control biped robot experiment.

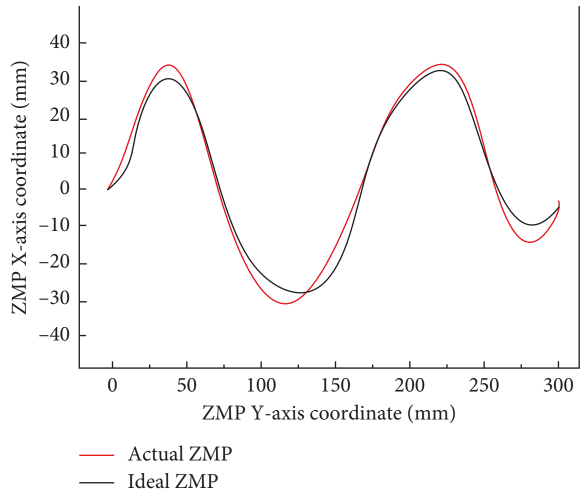

Figure 7: Ideal ZMP trajectory vs. Actual ZMP trajectory diagram.

5. Conclusion

The overall research level of biped robots not only reflects the development status of automation and intelligence in a country but also represents the overall scientific and technological strength of a country. With the rapid development of artificial intelligence technology and robots, the research of biped robots has become one of the frontier fields, attracting many researchers to join. The study of biped robots is not a coincidence of technical concepts, which is likely to have an impact on the long-term development of human history. Biped robots can be used to replace humans in some special environments, but some factors affect the robot's control performance, such as complex working environments, frequent interference, and unexpected external force disturbances. In order to avoid the possible impact of these factors on the robot, people need to design an efficient and robust balance control system. A stable gait constructed based on related theories can reduce the influence of external factors and the biped robot's own system, which can greatly improve its walking and the stability of the model. During the walking process of the biped robot, the swinging foot will produce a greater impact on the ground during the landing process, which will affect the walking stability of the robot to a certain extent. Therefore, in the next step, it is necessary to study the force of the biped robot's swing leg when it landed so as to ensure the stable walking of the biped robot. This is to facilitate the understanding of the control problems of the robot and help design the controller for the robot system. It is very necessary to have a comprehensive understanding of the mathematical model of the system.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest with any financial organizations regarding the material reported in this manuscript.

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