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Special Focus on Bio-Robotic Systems: Modeling, Design, Control and Perception

Gait planning and control method for humanoid robot using improved target positioning

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Humanoid robots have similar motion characteristics to humans and can be directly applied to human living space without modifying the existing environment. This characteristic makes the ability of humanoid robots to adapt to the human living environment better than non-humanoid robots such as wheeled robots. For example, it is difficult for wheeled robots to climb stairs, but humanoid robots can achieve this task through gait planning. For humanoid robots, it is important to maintain the stability of the humanoid robot while climbing stairs. Besides, the method of locating the position of the stairs is necessary. To realize the stair-climbing task of the humanoid robot, it is necessary to accurately locate the stair, plan the gait of the humanoid robot climbing stairs, and control the movement of the humanoid robot in real-time through the control system.

At present, the researches on stair-climbing tasks of humanoid robots mainly focused on gait planning, which was mostly based on the zero-moment point (ZMP) criterion. Sugahara et al. [1] proposed a gait planning method for biped robots climbing stairs, which was generated by preset ZMP trajectory. Kim et al. [2] proposed the univariate dynamic encoding algorithm for searches (uDEAS) for gait generation. Aguilera-Castro et al. [3] made the humanoid Nao recognize and climb the stairs by using the stereo vision-based method. Caron et al. [4] proposed a whole-body admittance control method for humanoid robot HRP-4, which focused on stair climbing stabilization and made HRP-4 climb 18.5 cm steps of stairs. In our previous study [5], Zhang et al. focused on the vision prescription-motion planning-control loop for the humanoid robot climbing stairs and implemented a 20 cm high staircase climbing using a full-size humanoid robot HRP-4. However, these methods need high real-time control and the algorithms are complicated. The localization of stairs requires the help of stereo vision, which is difficult for small humanoid robots. Therefore, it is necessary to develop a gait planning and positioning algorithm for the climbing environment of small humanoid robots.

In this study, we propose a method for humanoid robot Nao in the stair-climbing task which locates the position of stairs and plans the gait of climbing stairs. The stair position is located using landmarks based on a neural network fitting method. The gait of climbing stairs is divided into the trajectories of the center of gravity (COG) and the ankle joint, which based on the static walking method. To control the movement of the humanoid robot in real-time, we built a remote control platform and developed a control algorithm of motion. The proposed method is tested on the humanoid robot Nao and the results are given for demonstrating the effectiveness of the method.

Remote control platform and stair-climbing task

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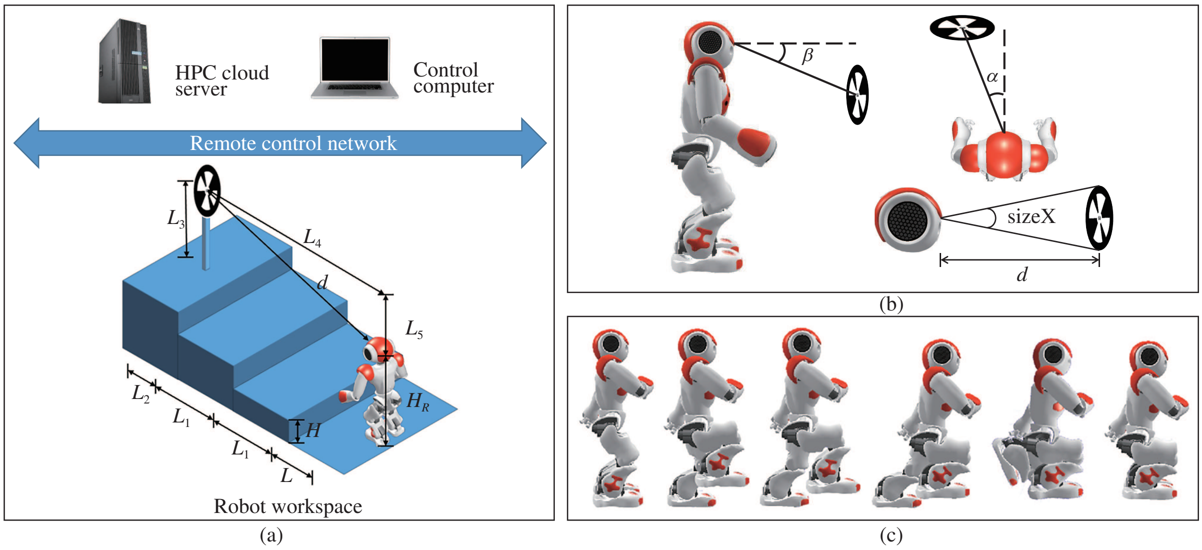

Figure 1 (Color online) (a) Remote control platform and robot workspace; (b) Naomark in the view of Nao robot; (c) gait design of climbing stairs.

environment for Nao robot. Nao H25 robot [6] is developed by the French Aldebaran Robotics Company, and it has a height of 57.3 cm and a weight of 5.4 kg, which is widely used as the experiment platform of the humanoid robot. To realize remote real-time control of Nao robots, the humanoid robot Nao control platform is developed. As shown in Figure 1(a), the HPC server is linked to the control computer via a wireless network, and the control computer is connected to the humanoid robot Nao via a wired network to increase the connection speed. The Nao robot performs tasks in the workspace, which contains multiple staircases. In this study, each step of the staircases has a height H of 2.94 cm and a length L_1 of 31.4 cm.

Stair localization based on Naomark. For the Nao robot to perform the stair-climbing task successfully, it is required for the precise localization of the stairs. The Nao robot has two cameras on the head, and they are located on the forehead and the mouth respectively, but the angle of view between the two cameras is small. It is difficult to form a binocular vision to achieve visual localization. For this reason, only the camera on the forehead of the Nao robot is used to construct the monocular vision with the help of auxiliary marks.

A Naomark is a black and white circular auxiliary mark. Its middle position has a serial number value to distinguish different Naomarks. When a Naomark is in the field of vision of the Nao robot, we can get the values of the maximum span angle sizeX, sizeY, the horizontal angle α, and the vertical angle β through the Naoqi framework. Figure 1(b) shows the Naomark and the parameters obtained in Naoqi. In our previous study [7], we used piecewise fitting to improve it based on the nonlinear relationship between sizeX and d. However, the accuracy of this method is still low when applied to longer distances.

Multilayer feedforward neural networks can be used as a general approximator to approximate any function [8]. Therefore, the neural network fitting method can be used to get the relationship between sizeX and d. To train the neural network, we collect 86 sets of data [sizeX, d], and use 50 sets as the training set and 36 sets as the test set. The neural network is built using the deep learning framework Pytorch. There are two neurons in the input layer, 128 neurons in the hidden layer, and 1 neuron in the output layer. We take [sizeX, sizeX^2] as the input to the neural network and the output is d. The activate function is ReLU, the loss function is L2 loss, and the neural network is trained by the SGD algorithm with the learning rate 0.001. After training the neural network, we can use it to predict the distance d from the Nao robot camera to the Naomark.

In Figure 1(a), there is a distance between the Nao robot and the step of stairs in the initial state. Therefore, this distance must be calculated so that the Nao robot moves to the stairs. According to geometrical relationship, we can get

$$\begin{cases} L_5 = L_3 + n \times H - H_R, \\ L_4 = \sqrt{d^2 - L_5^2}, \\ L = L_4 - L_2 - (n-1) \times L_1, \end{cases} \tag{1}$$

where d can be obtained using the neural network, H_R is the distance from the Nao robot camera to the ground, L_2 is the distance between the Naomark and the n-th step of stairs, L_3 is the height difference between the Naomark and the n-th step of stairs, and L is the distance between the Nao robot to the nearest step of stairs. The position of the stairs can be located according to L.

Gait planning for stair climbing. To complete the stair-climbing task, the gait for stair climbing must be designed for the Nao robot reasonably. The gait planning is based on static walking [9], which needs to keep COG inside the supporting polygons during the movement of the Nao robot.

Figure 1(c) shows the gait design of climbing stairs for the Nao robot. The process of climbing stairs can be divided into the following sub-processes. First, the Nao robot enters the initial posture and moves the COG from the center of the two feet to the left foot. Second, the Nao robot swings its right foot while moving the COG forward without going beyond the support polygon. Third, when the right foot of the Nao robot touches the stairs, the Nao robot moves the COG right to the center of both feet. Forth, the Nao robot moves the COG to the right and forwards at the same time until it moves to the right foot. Fifth, the Nao robot swings its left foot up the step and then moves the COG from the right foot to the center of the two feet. Finally, the Nao robot resumes its initial posture and prepares to climb the next step.

According to the gait design, the proposed method plans the trajectory of the COG and the ankle joint respectively. The trajectory of COG is divided into the forward and lateral processes. The forward trajectory is planned using the cubic spline interpolation method, and the lateral trajectory is planned using the inverted pendulum model. The trajectory of the ankle joint is only planned forward using cubic spline interpolation because the lateral process does not affect climbing stairs.

Control method. To integrate the gait planning and stairs localization and make the Nao robot perform the stair-climbing task, the control method is designed. When the program starts, the Nao robot will detect the Naomark in the field of view, and rotate the head so that the Naomark is in the center of the field of view according to the values of α and β returned by the Naoqi framework. According to the positioning method, the control system can obtain the positional relationship between the nearest stair step and the Nao robot. After that, the remote control platform controls the Nao robot to move to the nearest step and measures the position again. If the distance L_6 is acceptable, the Nao robot enters the initial posture. Otherwise, it continues to move to the nearest step. Then, the remote control platform generates the sequence of joint angles based on the pre-planned trajectory of the COG and the ankle joint and controls the Nao robot to climb the stairs. After this process, the Nao robot moves forward a short distance and begins to climb the next step. The control method is repeated until the Nao robot climbs the n-th step of stairs.

In the experiment, the proposed method successfully made the Nao robot climb 3 steps of stairs continuously and improved the accuracy of ranging results.

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Supporting information Videos and other supplemental documents. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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