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

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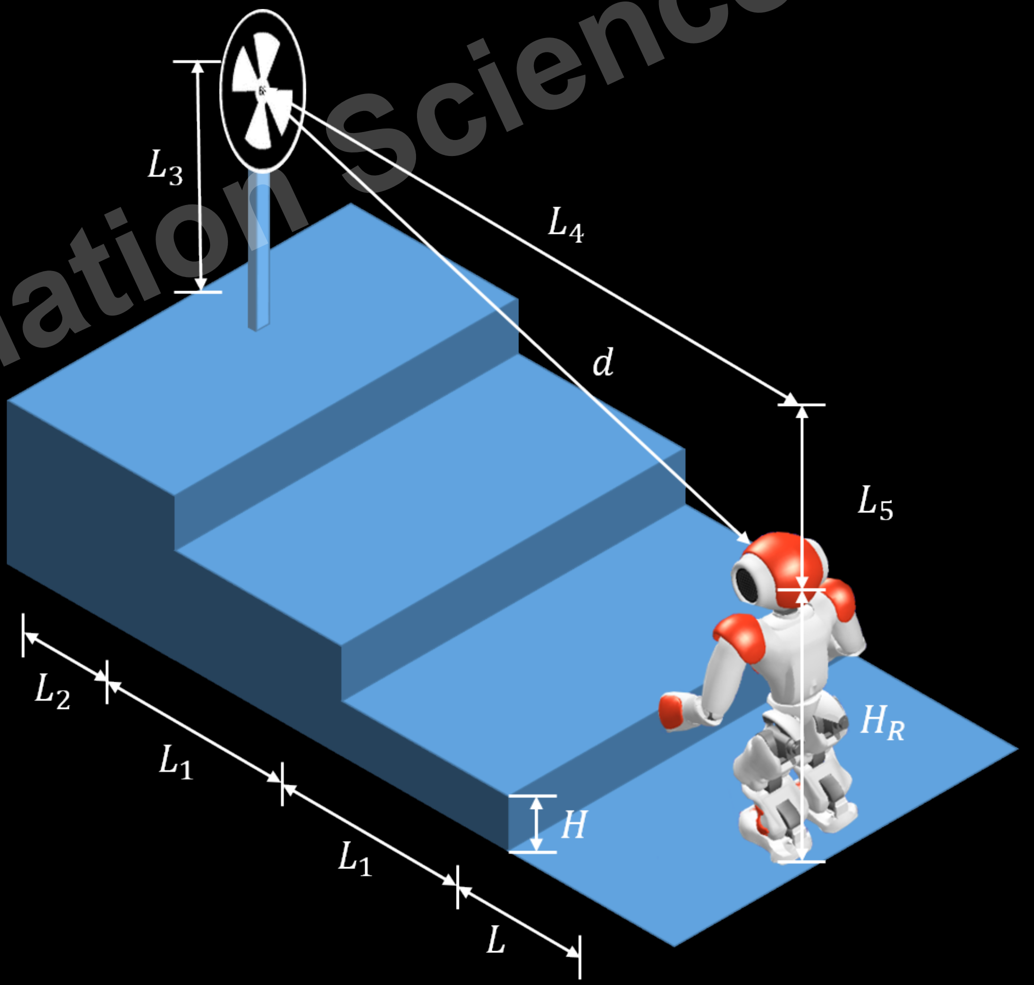
Introduction

The stair-climbing ability for humanoid robots is a prerequisite for robot application in complex environment. To deal with this task, it is necessary to focus on:

- Stair localization
- Gait planning
- Control method



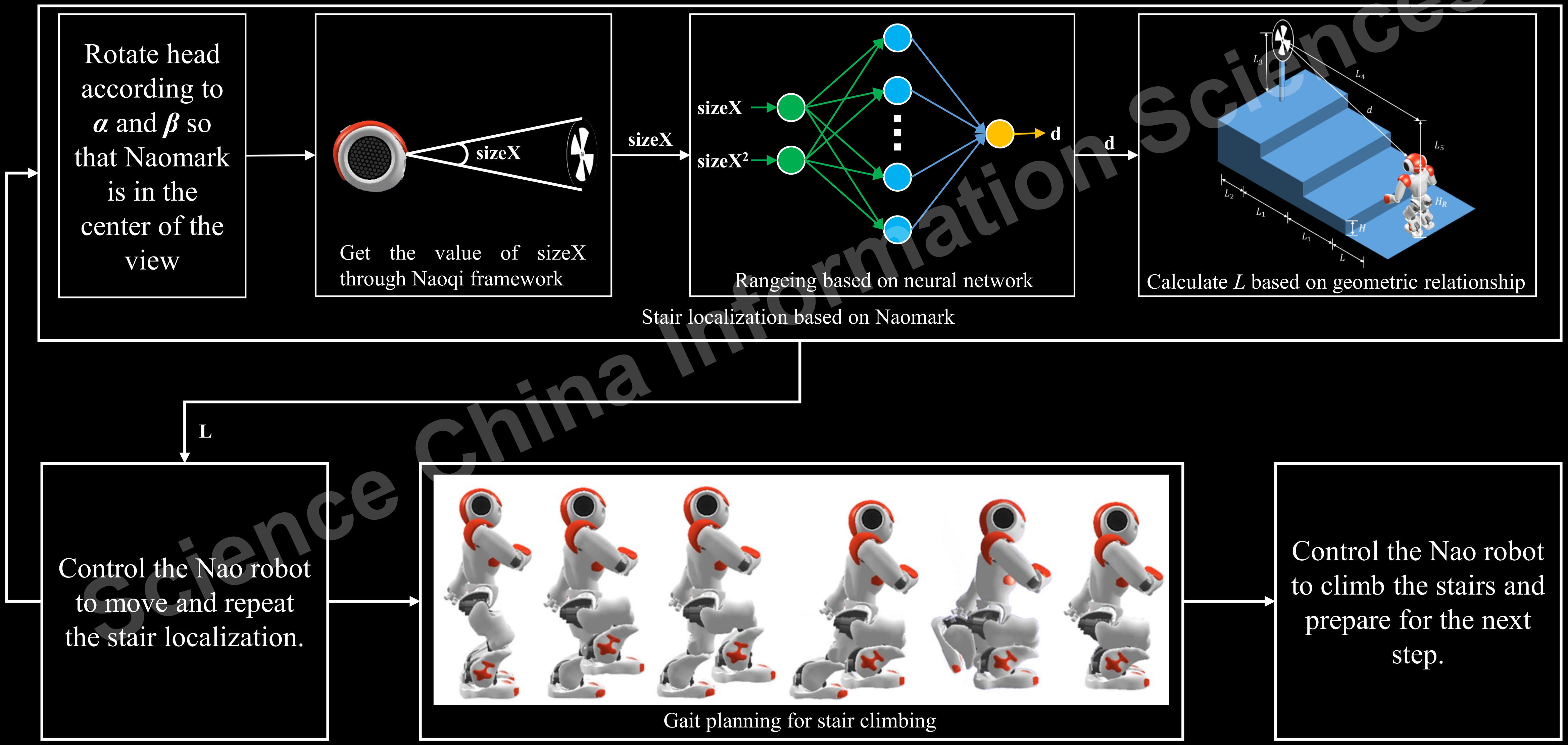
Stair-climbing environment for humanoid robots

Introduction

In this paper, we propose a method for humanoid robot Nao in the task of climbing stairs. The method contains the following parts:

- Stair localization based on Naomark: Three-layer fully connected neural network is used to obtain distance.
- Gait planning for stair climbing: The trajectories of COG and ankle joint are planned offline by the inverted pendulum model and the cubic spline interpolation method.
- Control method: Integrate the gait planning and stairs localization and make Nao robot climb stairs continuously.

System control flowchart

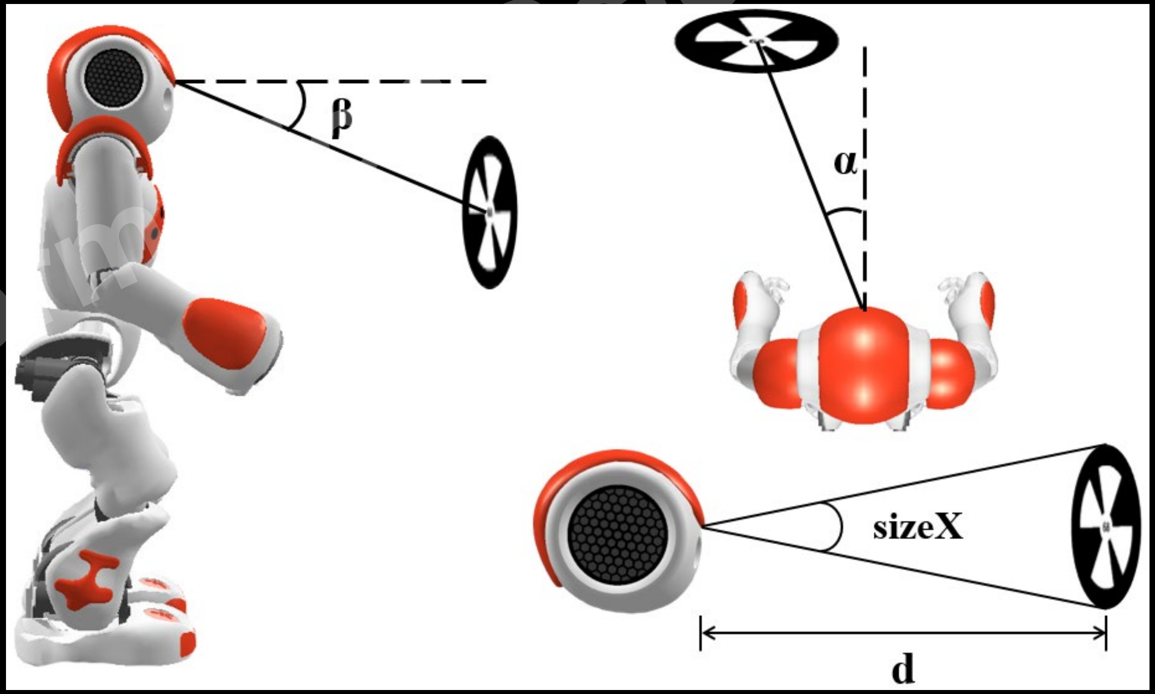


Stair localization based on Naomark

When Naomark is at the center of the field of view of the Nao robot. We can get the following relationship:

$$sizeX = \frac{pixle}{640} \times HOV \times \frac{\pi}{180}$$
$$sizeY = \frac{pixle}{480} \times VOV \times \frac{\pi}{180}$$

where $pixel$ is the pixel value of Naomark's diameter in the Nao camera, HOV is the maximum horizontal viewing angles, and VOV is the maximum vertical viewing angles, and $sizeX = sizeY$ in this condition. d is the distance from Naomark to the Nao robot camera.



Naomark in the field of the Nao robot

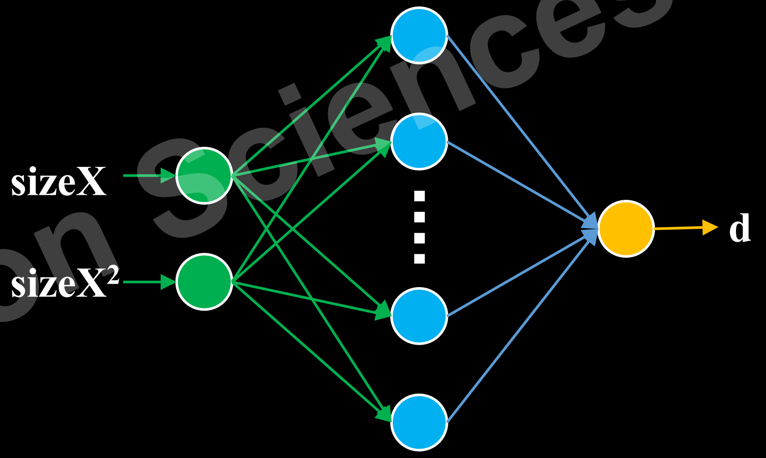
Stair localization based on Naomark

When Naomark is away from the Nao robot camera, the value of $sizeX$ will decrease. According to this, there is a non-linear relationship between parameters $sizeX$ and d, and we use multilayer feedforward neural networks to get this non-linear relationship for ranging.

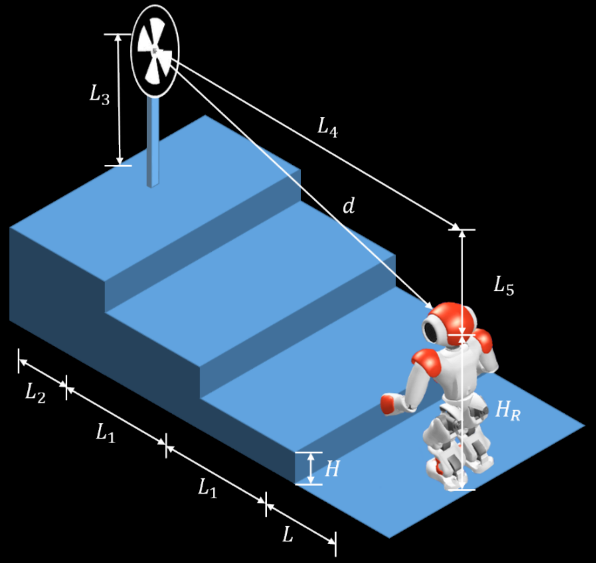
After get the value of d, we can get the distance between Nao robot and the nearest step by geometric relationship:

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

According to L, The position of the stairs can be located.



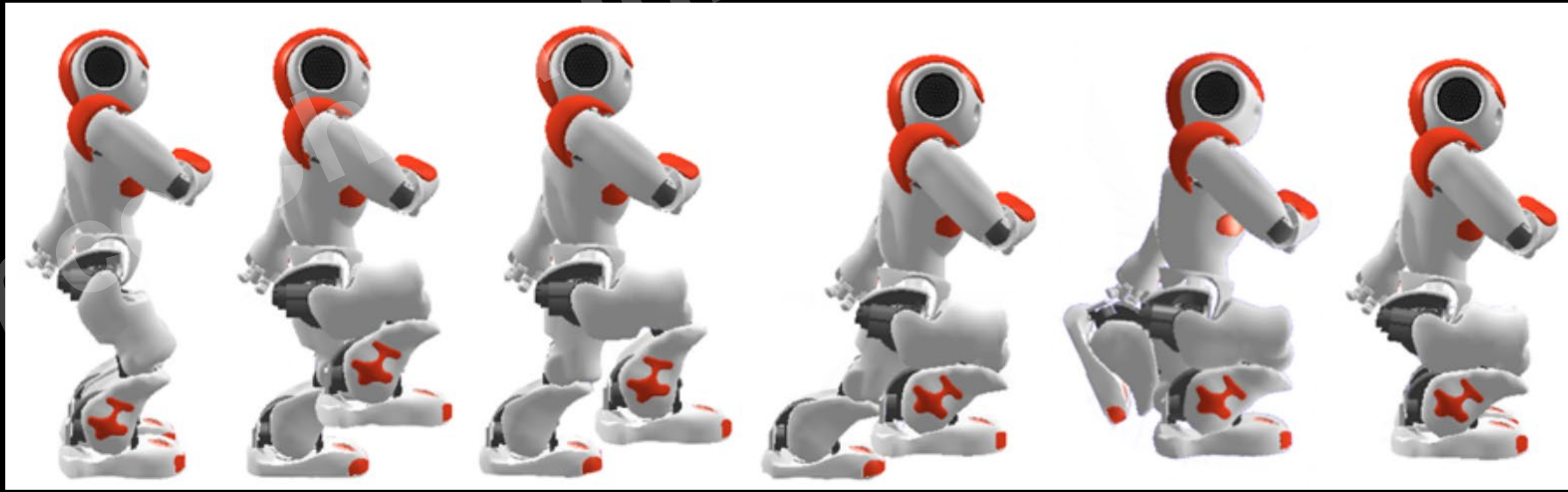
Neural network for ranging



Stair-climbing environment for humanoid robots

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 trajectories of COG and ankle joint are planned offline by the inverted pendulum model and the cubic spline interpolation method separately.



Gait design of climbing stairs

Gait planning for stair climbing

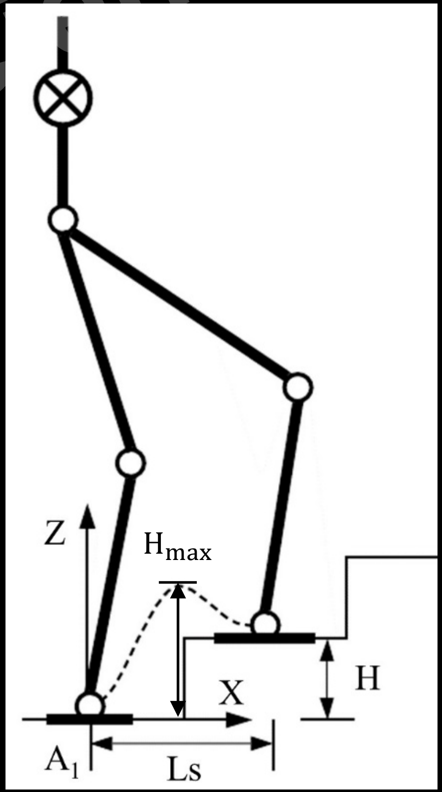
The trajectories of ankle joint are planned by the cubic spline interpolation.

The ankle joint is A_2 (x_2, y_2, z_2), and y_2 is ignored. The trajectories of x_2 and z_2 are obtained by the following formula:

$$x_2(t) = \frac{-2L_s}{T^3}t^3 + \frac{3L_s}{T^2}t^2 \quad ,0 \le t \le T$$

$$z_2(t) = \frac{8H_{max}\left(\frac{3}{2}T - 2t\right)t^2 + 6H\left(t - \frac{T}{2}\right)t^2}{T^3} \quad ,0 \le t \le \frac{T}{2}$$

$$z_2(t) = \frac{8H_{max}\left(2t - \frac{T}{2}\right)(t-T)^2 + 6H\left(t - \frac{T}{2}\right)(t-T)^2 + 8H(\frac{5}{2}T - 2t)(t - \frac{T}{2})^2}{T^3} \quad ,\frac{T}{2} < t \le T$$



The ankle joint motion of swinging leg

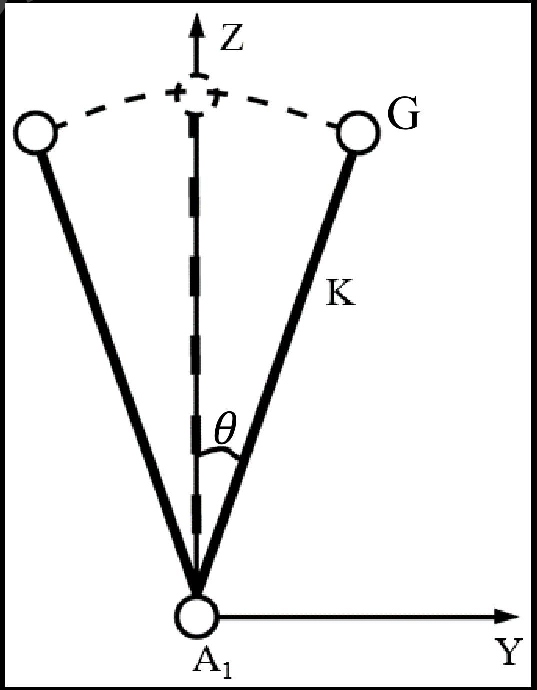
Gait planning for stair climbing

The trajectories of is planned by the inverted pendulum model and the cubic spline interpolation method. The linear inverted pendulum model is used to plan the lateral motion trajectory of the robot.

The COG is $G\ (x_0, y_0, z_0)$, and z_0 is ignored in lateral process. Let θ be the swing angle of the inverted pendulum, the relationship between θ and K is

$$\ddot{\theta}(t) = \frac{g}{K} sin\theta(t)$$

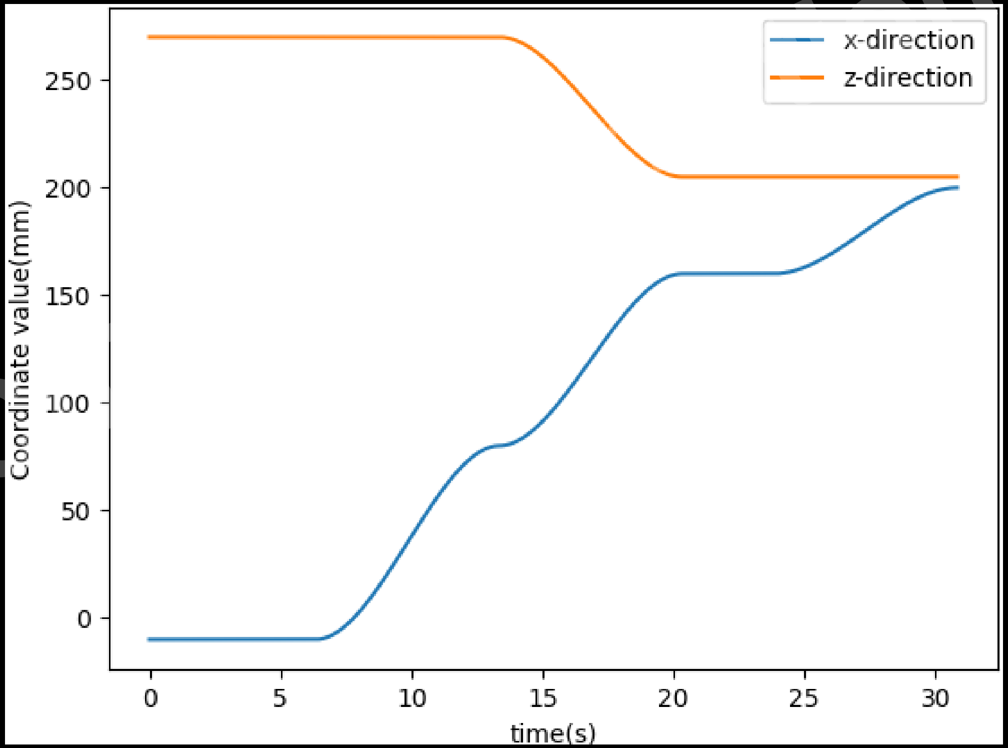
where g is acceleration of gravity.



The linear inverted pendulum model

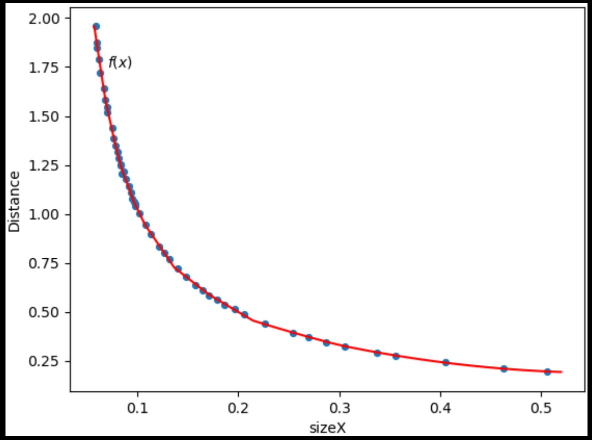
Gait planning for stair climbing

The trajectories of COG forward $G\ (x_0, z_0)$ is planned by the cubic spline interpolation method.

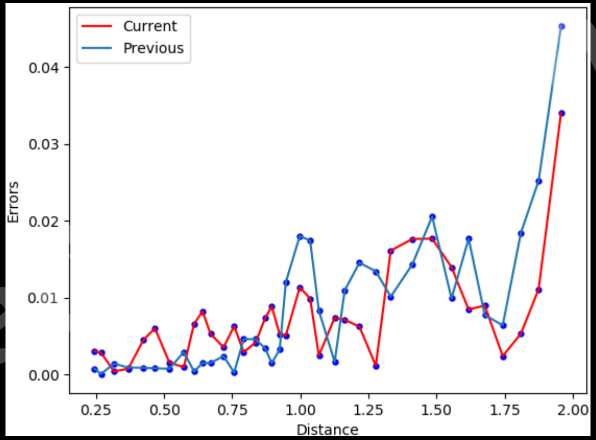


The planning trajectory of COG forward

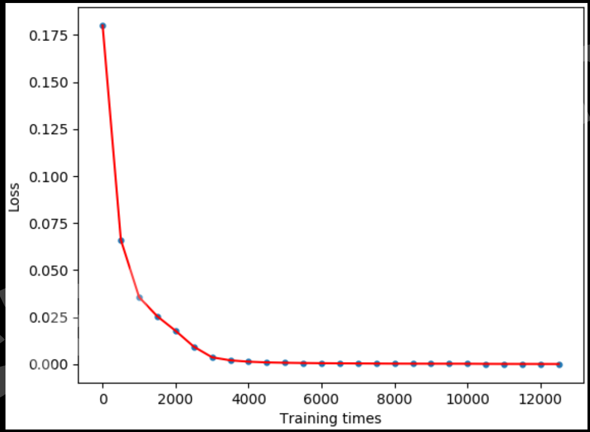
Results



Fitting to neural network



The statistics of errors



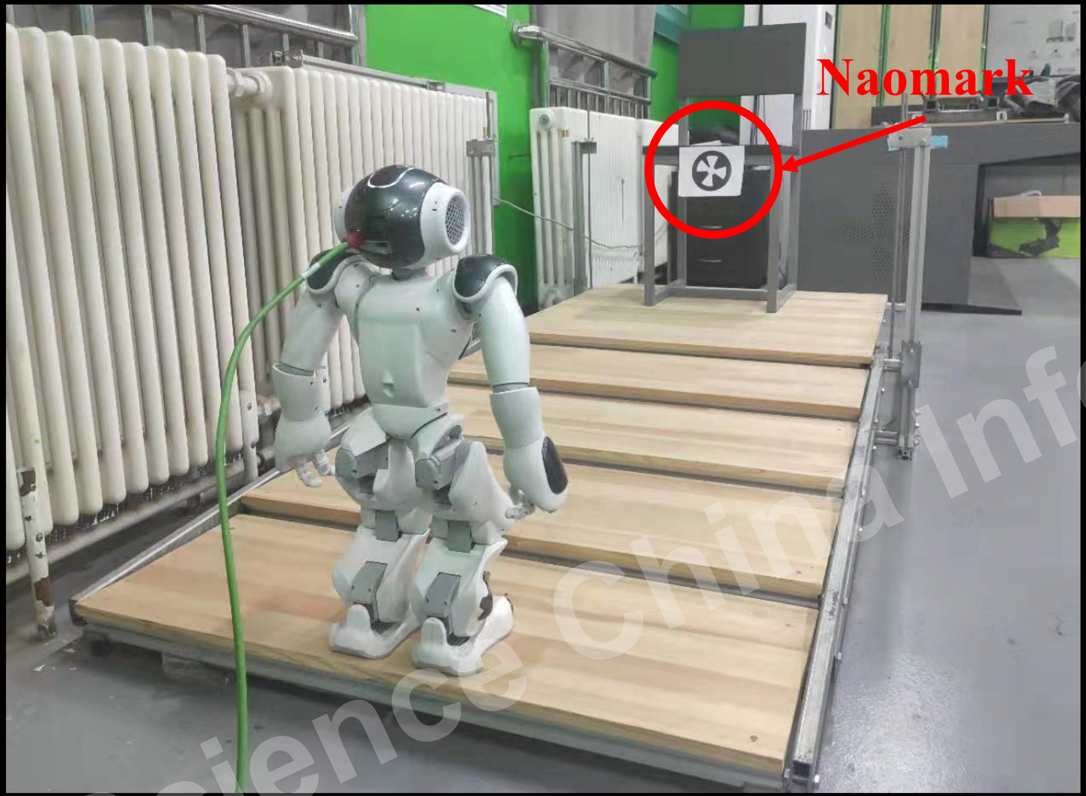
Loss during trainging process

The statistics of the accumulative error

Distance	Current errors (m)	Previous errors (m)	Improvement
0.9m-2m	0.18626	0.27209	31.54%
0.2m-2m	0.26466	0.30366	12.84%

The accuracy of ranging has been improved by 12.84%.

Results



Experimental environment

1.587 m — Step 1

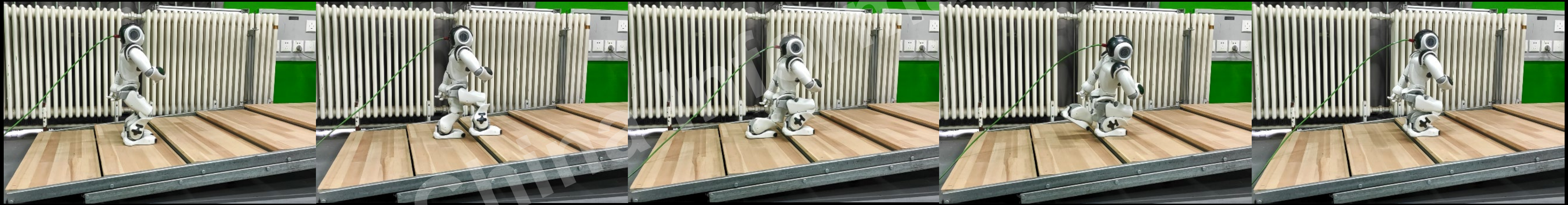
1.293 m — Step 2

0.983 m — Step 3

The results of ranging in each step

Results

Step 1



Step 2

Step 3

The experiment of Nao robot climbing stairs

Thanks