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Foot trajectory and gait planning of quadruped robot

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Abstract: Foot trajectory and gait planning is one of the important research fields of foot robot. The eighth order polynomial is used to plan the trajectory of each joint of the robot leg, so that the Angle, angular velocity and angular acceleration curves of each joint during leg movement can be smooth and continuous, so as to improve the smooth and quick action of the leg movement. Through MATLAB simulation and robot experiment, it is proved that the eight-order polynomial can keep the legs of the robot continuously and smoothly in the process of movement, reduce the impact of the mutation of the joint movement on the legs of the robot, so that the running trajectory of the robot can be optimized to a certain extent.

Keywords: Quadruped robot; Octave polynomial; Foot trajectory planning.

1. Introduction

The gait planning of hexapod robots plays an important role in realizing the free control function of multi-legged robots, which puts forward high requirements for the rapidity and stability of robots when moving. Good gait planning can not only help robots to adjust stably to adapt to different environments. Moreover, it can effectively improve the walking speed of the robot and reduce the energy consumption. For the gait planning of hexapod robot, it is necessary to consider the structure of the robot itself and refer to the walking mode of natural creatures.

2. Foot trajectory planning

In order to obtain an ideal foot trajectory, foot trajectory planning needs to meet the following conditions: 1) all joints move gently without sudden acceleration or deceleration; 2) The leg moves smoothly without obvious swing and impact; 3) swing leg lift and landing moment no impact; 4) Smooth foot track, swing phase leg lift quickly; 5) Joint rotation velocity and acceleration are smooth and continuous without abrupt change; 6) Avoid sliding when the foot contacts with the ground, and do not swing the leg to mop the ground .

According to the above requirements, the movement period of single leg is set as T, $0 \sim \frac{T}{2}$as swing phase, $\frac{T}{2} \sim T$as support phase, the direction of travel is X direction, the direction of leg lifting is Z direction, the step length is S, and the height of leg lifting is H. According to the requirements of foot trajectory planning, the constraints of satisfied end trajectory in X direction and Z direction are as follows

2.1. Horizontal X direction

Position constraints: the initial position is 0, the end position of the swing phase is 0, and the end position of the support phase is 0. That is:

$$x(0) = 0 \tag{1}$$
$$x(T/2) = S \tag{2}$$
$$x(T) = 0 \tag{3}$$

constraint of velocity

$$\dot{x}(0) = 0 \tag{4}$$
$$\dot{x}(T/2) = 0 \tag{5}$$
$$\dot{x}(T) = 0 \tag{6}$$

Acceleration constraint

$$\ddot{x}(0) = 0 \tag{7}$$
$$\ddot{x}(T/2) = 0 \tag{8}$$
$$\ddot{x}(T) = 0 \tag{9}$$

It can be seen from the above that there are 9 constraints in the X direction. In the X direction, the trajectory of the oscillating phase is the same as that of the supporting phase, and only the direction changes. In order to reduce the amount of calculation, only the trajectory of the oscillating phase is considered. It can be seen from above that there are only 6 constraints on the oscillating phase in the X direction, so the foot trajectory in the horizontal direction is assumed to be a quintic polynomial:

$$x = at^5 + bt^4 + ct^3 + dt^2 + et + f \tag{10}$$
$$\dot{x} = 5at^4 + 4bt^3 + 3ct^2 + 2dt + e \tag{11}$$
$$\ddot{x} = 10at^3 + 6bt^2 + 3ct + 2d \tag{12}$$

Let's say that the period of the oscillating phase is T0, plug in the constraint equation,

$$x(0) = 0 \quad x(T_0) = S \tag{13}$$
$$\dot{x}(0) = 0 \quad \dot{x}(T_0) = 0 \tag{14}$$
$$\ddot{x}(0) = 0 \quad \ddot{x}(T_0) = 0 \tag{15}$$

Acquirability

$$a = \frac{6S}{T_0^5} \quad b = -\frac{15S}{T_0^4} \quad c = \frac{10S}{T_0^3} \quad d = e = f = 0 \tag{16}$$

Be

$$x = \frac{6S}{T_0^5}t^5 - \frac{15S}{T_0^4}t^4 + \frac{10S}{T_0^3}t^3 \tag{17}$$
$$\dot{x} = \frac{30S}{T_0^5}t^4 - \frac{60S}{T_0^4}t^3 + \frac{30S}{T_0^3}t^2 \tag{18}$$
$$\ddot{x} = \frac{120S}{T_0^5}t^3 - \frac{180S}{T_0^4}t^2 + \frac{60S}{T_0^3}t \tag{19}$$

Set the period of swing phase to 1 and step length to 100. The position, velocity, and acceleration curves are shown in Fig.1.

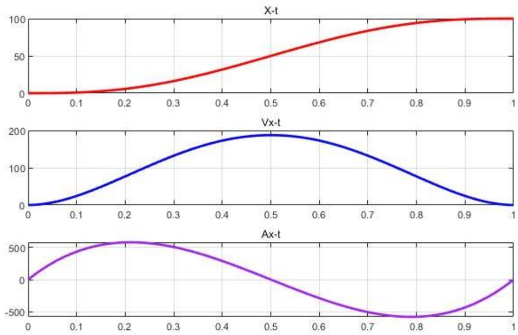

Fig.1 X direction position, velocity, and acceleration curves

2.2. Vertical Z direction

Position constraints: the initial position is 0, the end position of the swing phase is 0, and the end position of the support phase is 0. That is:

$$x(0) = 0 \tag{20}$$

$$x(T/2) = H \tag{21}$$

$$x(T) = 0 \tag{22}$$

$$\dot{x}(T/2) = 0 \tag{23}$$

$$\dot{x}(T) = 0 \tag{24}$$

Acceleration constraint

$$\ddot{x}(0) = 0 \tag{25}$$

$$\ddot{x}(T/2) = 0 \tag{26}$$

$$\ddot{x}(T) = 0 \tag{27}$$

It can be seen from the above that there are 9 constraints in the vertical direction, and the foot trajectory in the vertical direction is assumed to be a polynomial of eight times, namely:

$$x = At^8 + Bt^7 + Ct^6 + Dt^5 + Et^4 + Ft^3 + Gt^2 + Ht + I \tag{28}$$

$$\dot{x} = 8At^7 + 7Bt^6 + 6Ct^5 + 5Dt^4 + 4Et^3 + 3Ft^2 + 2Gt + H \tag{29}$$

$$\ddot{x} = 56At^6 + 42Bt^5 + 30Ct^4 + 20Dt^3 + 12Et^2 + 6Ft + 2G \tag{30}$$

Plug in the constraint and solve it with MATLAB

$$A = -(768 \cdot H)/T^8 \tag{31}$$

$$B = (3072 \cdot H)/T^7 \tag{32}$$

$$C = -(4864 \cdot H)/T^6 \tag{33}$$

$$D = (3840 \cdot H)/T^5 \tag{34}$$

$$E = -(1536 \cdot H)/T^4 \tag{35}$$

$$F = (256 \cdot H)/T^3 \tag{36}$$

Then the vertical foot trajectory equation is:

$$x = -\frac{768 \cdot H}{T^8}t^8 + \frac{3072 \cdot H}{T^7}t^7 - \frac{4864 \cdot H}{T^6}t^6 + \frac{3840 \cdot H}{T^5}t^5 - \frac{1536 \cdot H}{T^4}t^4 + \frac{256 \cdot H}{T^3}t^3 \tag{37}$$

$$\dot{x} = -\frac{6144 \cdot H}{T^8}t^7 + \frac{21504 \cdot H}{T^7}t^6 - \frac{29184 \cdot H}{T^6}t^5 + \frac{19200 \cdot H}{T^5}t^4 - \frac{6144 \cdot H}{T^4}t^3 + \frac{768 \cdot H}{T^3}t^2 \tag{38}$$

$$\ddot{x} = -\frac{43008 \cdot H}{T^8}t^6 + \frac{129024 \cdot H}{T^7}t^5 - \frac{145920 \cdot H}{T^6}t^4 + \frac{76800 \cdot H}{T^5}t^3 - \frac{18432 \cdot H}{T^4}t^2 + \frac{1536 \cdot H}{T^3}t \tag{39}$$

Set the period of swing phase to 1 and lift leg height to 30. The position, velocity and acceleration curves are shown in Fig. 2.

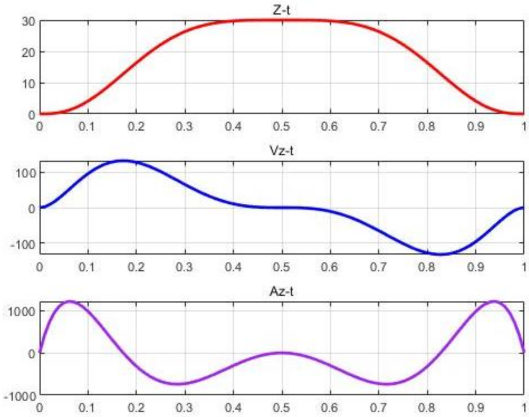

Fig.2 Z-direction position, velocity, and acceleration curves

3. Conclusion

According to the trajectory curve of the foot in joint space, it can be seen that the position of the points passed by the robot's foot is consistent with that of the planned points, and the trajectory curve is smooth and continuous, indicating that the eighth order polynomial can be successfully applied to the trajectory planning of the foot. The trajectory curves of the Angle, angular velocity and angular acceleration of each joint of the robot's legs are smooth and continuous, and there is no mutation in the acceleration and deceleration process, which can make the robot's feet land stably and reduce the impact of Angle changes on the legs, so as to realize the smooth and rapid movement of the robot's legs.

References

[1] Chen Yu. In welding magnetic adsorption crawler walking robot design and path planning [D]. Harbin commercial university, 2020. The DOI: 10.27787 /, dc nki. GHRBS. 2020.000334.

[2] Liu Junfeng. Large steel structure inspection climbing robot developed [D]. Nanjing forestry university, 2021. The DOI: 10.27242 /, dc nki. Gnjlu. 2021.000248.

[3] Wen Jing. Design and Characteristics of Tank Wall Crawling Robot [D]. Shanghai Jiao Tong University,2011.

[4] Li Wei, Jin Fanyao, Duan Yuchao, Wang Wenxiang, Tuo Qi, Luo Yongcheng. Chinese Patent: CN104048139B,2014.09.17. A Magnetic Seat Type Iron Wall Adaptive Crawling Robot [P]

[5] Zhao Qianjun, Hu Penghao, Han Xuefeng. Research on Ultrasonic Detection of Fatigue Crack of Crank Pin Device in Pumping Unit [J]. Industrial Metrology,2012,(6): 1-3, 5.

[6] Xu Jin. Leech adsorption mechanism research and bionic chuck chuck high-performance design [D]. Jilin university, 2021. The DOI: 10.27162 /, dc nki. Gjlin. 2021.006864.

[7] Shen Qingqing. Design and Research of Wall Climbing Robot for Magnetic Particle Detection [D]. Zhejiang University of Technology,2014. Modeling and Simulation of Small wall-climbing Cleaning Robot based on ADAMS [J]. Journal of Nanchang University (Engineering Edition),2012, (3): 248-252

[8] Wu Lingfeng. GIS development of quadruped robot climbing wall internal fault detection [D]. South China university of technology, 2021. The DOI: 10.27151 /, dc nki. Ghnlu. 2021.003832.

[9] Xie Huixiang. Research on Intuitive Control Method of Virtual Model for Quadruped Robot Diagonal Trotting Gait [D]. National University of Defense Technology,2015.

[10] Li Yue. Quadruped robot gait planning strategy research [D]. Shanghai ocean university, 2022. The DOI: 10.27314 /, dc nki. Gsscu. 2022.000573.

[11] Wang Shuguang, Ed. Wang Shuguang, Yuan Lixing, Zhao Yong, Ed. Principle and Design of Mobile Robot [M]. Beijing: Posts and Telecommunications Press,2013

[12] Xie Jiaxing. Research on Stable Motion Control Technology of Quadruped Robot in Unstructured Environment [D]. Nanjing University of Aeronautics and Astronautics,2018.

[13] Wang Pengfei. Research on Stable Walking Planning and Control Technology of Quadruped Robot [D]. Harbin Institute of Technology,2007.

[14] Liu, Yanheng; Lim, Byoungduk; Lee, Jehwon; Park, Jihyuk; Kim, Taegyun; Seo, Taewon.Steerable dry-adhesive linkage-type wall-climbing robot.[J].Mechanism & Machine Theory,2020,Vol.153: 103987

[15] Zhang Chengwei. Climbing robot design and analysis of tank [D]. Southwest petroleum university, 2019. The DOI: 10.27420 /, dc nki. Gxsyc. 2019.000388.

[16] Zhang Qing-song, Duan Shuai-chen, Xia Re. Work Space Analysis and Simulation of Anthropomorphic Manipulator Based on Matlab [J]. Journal of Mechanical Transmission,2020, Vol. 44 (12): 99-105

[17] Liu Xuefei. Kinematics and Dynamics Performance Analysis and Software Development of Palletizing Robot [D]. Xi 'an University of Technology,2015.

[18] In full bloom. Research on Kinematics and Cooperative Space of Robot Modular Two Arms [D]. Anhui University of Science and Technology,2019.

[19] Zhou Jiajun. Application and Simulation of Mobile Manipulator System in Warehousing Field [D]. Zhejiang University of Technology,2018.

[20] Ji Cheng. Modeling and Simulation of Upper Limb Rehabilitation Robot System [D]. Northeastern University, 2010.

[21] Chen Jie. The design of the lower limb rehabilitation exoskeleton robot driven by pneumatic muscle and research [D]. Chongqing jiaotong university, 2021. The DOI: 10.27671 /, dc nki. GCJTC. 2021.000412.

[22] Lei Zhiming. Mechanical arm grasping pose estimation based on RGB image research [D]. Guangxi university, 2021. The DOI: 10.27034 /, dc nki. Ggxiu. 2021.001179.

[23] Fu Jiaxin. Research on Modeling and Control of Table Tennis Manipulator [D]. Shandong University,2017.

[24] Zhang Wenlu, Wang Hong, Lei Chao, Wang Linlin, Sha Hong. Terminal attitude analysis and motion planning based on UR3 robotic arm puncture navigation [J]. International Journal of Biomedical Engineering,2021, Vol 44 (2): 95-100,112.