Six-legged Walking Robot's Gait Planning and Kinematics Analysis under the Environment of Concave Ground

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Abstract. Legged robot has advantages with high degree of freedom, flexibility and strong adaptability to the ground. So this paper presents a posture in concave ground environment of a leg organization of a six-legged robot and proposes a gait planning of six-legged robot, which ensure it to move smoothly and efficiently. Using homogeneous and rotational homogeneous transformation to analyze the kinematics model of standing leg and swinging leg, and then calculate the kinematics equation. It lays the foundation for the further study of the motion control of robot.

Preface

With the continuous expansion of the robot field, the variety of the robot is becoming more and more abundant. Distinguishing the robot by moving style, it can be divided into wheeled robots, legged robots and crawler robots. Compared with wheeled robot crawler, legged robots have some advantages. The legs of legged robots have a lot of freedom which can guarantee robots to move more flexibility, and these robots have a good ability to adapt in rugged terrain[1]. Because of the robots' footholds are discrete, and contact area with the ground is small, so the robots can choose the best place to make itself more stable in walking process. Therefore, the research of legged walking robots has become an attractive area. In 1989, the MIT Artificial Intelligence Laboratory developed a six-legged robot Genghis[2]; In 1995, Laboratory of mechanical and Aerospace Engineering College[3], Case Western Reserve University developed a six-legged robot Robot Ⅱ [4]; In 2001, the German Fraunhofer Institute for Autonomous Intelligent Systems developed a robot Scorpion[5]. More than four-legged robots are called multi-legged robots, these robots can replace humans working in some special or dangerous environment. For the pipeline robots research, robots move in a certain radius of curvature of concave ground is similar to moving in a horizontal pipe, it has a certain reference value for the robot's movement of the pipe research. Comprehensive analysis, this article chooses six-legged walking robot, proposes a gait planning and analyses the kinematics of standing leg and swing the leg.

Six-legged robot gait planning

The concave surface with a range of radius of curvature belongs to one of the special environment, the robots' walking in this environment is different from on a flat surface, this robot needs to be better stability and preventing the roll, so, the robot needs to have a specific mechanism to guarantee the stability of the robot's movement. Figure 1 is a sectional view of the robot, O is the center of the concave surface, ideally, we put the ground as a standard concave, A and B on behalf of the robot's foot and the ground contact point.
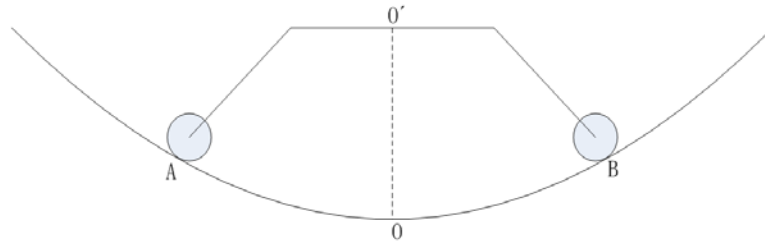
Figure 1 Sectional view of robot in the concave

The so-called triangle gait is divided the robot's six feet into two groups, one side of the front feet, back feet, and on the other side of the feet is divided as a group, the rest of the feet are divided as a group, the movement of each group is consistent and it can constitute a tripod to support the body, so, the robots of the six feet have strong stability[6].
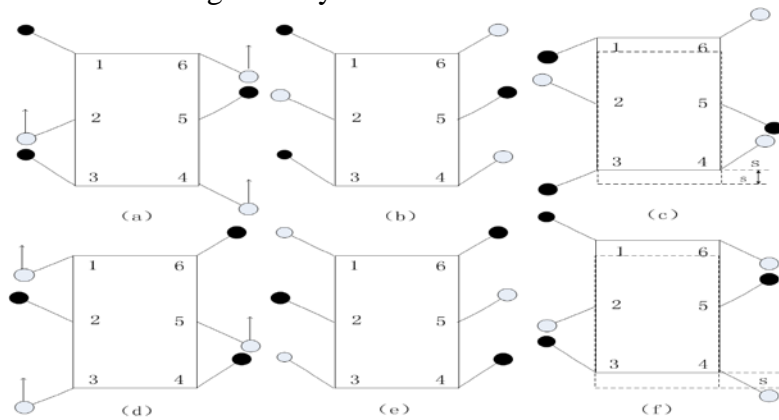

Figure 2 walking gait of the six-legged robot

Figure 2 is the walking gait of the six-legged robot , the solid dot represents the robots' standing leg, the modesty of the dot represents the robots' swing leg, as the movement way, the legs 1, 3, 5 were divided into a group, the legs 2, 4, 6 were divided into another group, and legs 2, 4, 6 lift as swing legs, in order to keep balance, The center of gravity of robot is coincident with that of the triangle area formed by the legs 1, 3, 5 , at this time, the legs of 1, 3, 5 support the whole body as standing legs, as is shown in figure a; The swing legs step forward, as is shown in figure b; at this time, as the standing legs , legs 1, 3, 5, have the effect of supporting the whole body on one hand and driving the body forward a step size S by DC driving motor and belt driving mechanism on the other hand, as shown in figure c; When the robot complete mobiling, the legs 2, 4, 6, fall to the ground to support the body as standing legs, the centre of gravity of the robot falls in the stable triangle area formed by three legs ,at this time , legs 1, 3, 5 raise and ready to step up to move as the swinging legs, the legs 2, 4, 6 support the whole body as supporting legs , in order to ensure that the robot can stand stably, the gravity of the robot fall the triangle area formed by the supporting legs, as is shown in figure d; The swing legs of 1, 3, 5 take a step forward, as is shown in figure e; As the standing legs of 2, 4, 6, have the effect of supporting the whole body on one hand and driving the body forward a step size s on the other hand, as is shown in figure f. So, a—b—c—d—e—f is a motion cycle of the robot.

The gait is dividing six legs into two groups when the robot is turning which is similar to going straight, And the only difference is that the three legs of turning side move toward the opposite direction. For example, when the robot is turning right, the left side of the three legs swing in accordance with the normal motion, while the right side of the three legs swing as nomal in the opposite direction, but the movement speed of the three legs is consistent with the previous, this is turning on the spot of the robot, it also to say that when robot is turning, the robot's displacement doesn't change.

Kinematics Analysis

Standing leg kinematics analysis.

The so-called positive kinematics of standing leg is that calculating the joint of the robot's hip in the reference coordinate system based on the known robot foothold posture and the robot joints

variable values, And since the hip joint is connected with robot's body, The posture of hip joint is same with that of the robot's body[7]. The mathematical description of the geometric relationship between each connecting rod on the leg、 the robot body and the ground is very important. These relationships are established by coordinate system, and homogeneous transformation is an important solution to this kind of problem as homogeneous transformation matrix is used to describe the position and direction of the robot body in three dimensional space[8].
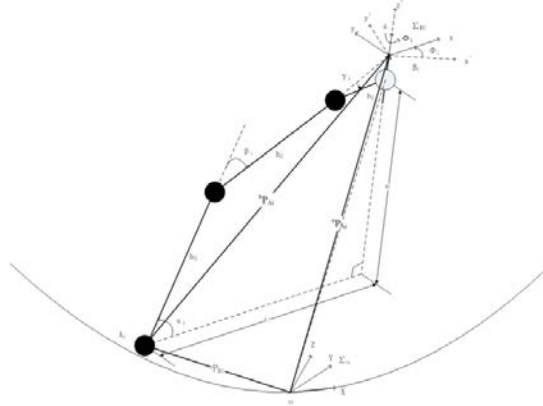

Figure 3: Posture of the robot standing leg

As shown in figure 3, α_i、 β_i and γ_i describe the aggregation relationships between connecting rod plane and the contacted ground(ground that is contacted). Hip joint is fixed on the robot body and ϕ_i is the direction relationship between connecting rod plane and robot body, in order to facilitate the statements of the following calculation, ϕ_i is defined as the angle between connecting rod plane and the x axis in $\sum_{B_i}$ according to the right-hand rule.

Translation transformation is translational homogeneous transformation, represented by formula (3.1).

$$\text{trans}(x) = \begin{bmatrix} I_{3*3} & x \\ 0 & 1 \end{bmatrix} \tag{3.1}$$

Rotating homogeneous transformation represented by the formula (3.2).

$$\text{rot}(k, \theta) = \begin{bmatrix} R(k, \theta) & 0 \\ 0 & 1 \end{bmatrix} \tag{3.2}$$

$R(k, \theta)$ is the spin operator, it represents matrix of the new coordinate system orientation after that the coordinate system rotates degrees around the axes of k, the matrix can be described as below when k axes as x, y, z axes respectively:

$$R(x, \theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \tag{3.3}$$

$$R(y, \theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \tag{3.4}$$

$$R(z, \theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3.5}$$

We assume that the initial $\sum_{B_i}$ and $\sum_o$ overlap, then make translation transformation and rotation transformation from Ai to Bi, and get the position and direction of $\sum_{B_i}$ through homogeneous transformation, As is showed in figure (3.6).

$$T_{B_I} \text{trans}\left({}^o x_{A_i}, {}^o y_{A_i}, {}^o z_{A_i}\right) \text{rot}(z, \alpha_i) \text{trans}(0,0, h_3) \text{rot}\left(y, \beta_i\right) *$$
$$\text{trans}(0,0, h_2) \text{rot}\left(y, \gamma_i\right) \text{trans}(0,0, h_1) \text{rot}\left(y, -\frac{\pi}{2}\right) \text{rot}(z, \Phi_i) \tag{3.6}$$

$\left[{}^o x_{A_i}, {}^o y_{A_i}, {}^o z_{A_i}\right]$ is the origin of A_i in the three-dimensional coordinates,and ${}^o x_{A_i}, {}^o y_{A_i}, {}^o z_{A_i}$ represent the direction vector that the x, y, and z-axis in Σ_o with respect to Σ_o. And equation (2.6) can be expanded as follow:

$$T_{B_i} = \begin{bmatrix} R_{B_i} & {}^oP_{B_i} \\ 0 & 1 \end{bmatrix} \tag{3.7}$$

Detailed approach is not explained here now. Type (3.7) is the standing leg positive kinematics solution, that is mean the hip joints position is determined by a given joint angle, since the hip joint shaft fixed on the robot body, so actually T_{B_i} gives the posture of robot body.

The calculation of forward kinematics of the swinging leg.

The analysis of forward kinematics of the swinging leg is similar to the way of standing leg, they both determine the position of robot feet in the reference frame by the using the posture of the robot and the driven joint-variate of legs[9,10].
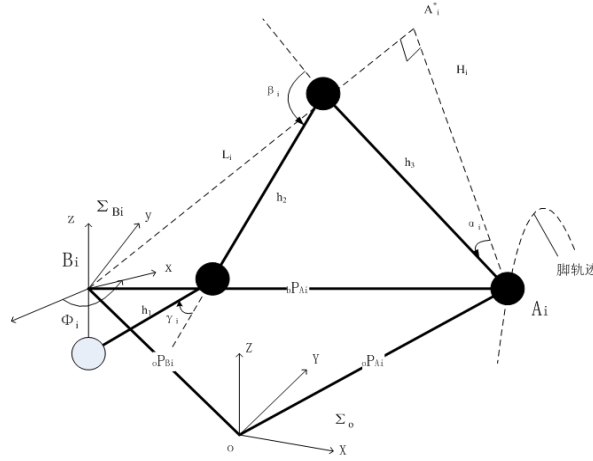

Figure 4 Posture of the robot swinging leg

Figure 4 shows the legs of the robot swinging to a certain position, we can get the following equation

$$^oP_{A_i} = {}^oP_{B_i} + R_{B_i}{}^bP_{A_i} \tag{4.1}$$

$$\begin{bmatrix} {}^bx_{A_i} \\ {}^by_{A_i} \\ {}^bz_{A_i} \end{bmatrix} = \begin{bmatrix} L_i\cos(\pi - \Phi_i) \\ L_i\sin(\pi - \Phi_i) \\ -H_i \end{bmatrix} \tag{4.2}$$

$^oP_{A_i}$——the position vector in the reference frame of Σ_o of A_i

$^oP_{B_i}$——the position vector in the reference frame of Σ_o of B_i

R_{B_i}——the direction matrix of B_i

$^bP_{A_i}$—— the position vector of a foothold of Σ_{B_i}, $^bP_{A_i} = \begin{bmatrix} {}^bx_{A_i} & {}^by_{A_i} & {}^bz_{A_i} \end{bmatrix}^T$

$$\begin{cases} L_i = h_1 + h_2\cos\gamma_i + h_3\cos(\gamma_i + \beta_i) \\ H_i = h_2\sin\gamma_i + h_3\sin(\gamma_i + \beta_i) \end{cases} \tag{4.3}$$

h_1、h_2、h_3 presents the length of the robot between the two joints, L_i presents the extension length of the legs of the xy plane of Σ_{B_i} , H_i presents the extension length of the legs on the z axis stretching.

At this point, we plug the formula 4.1 in the formula 4.2, and get the following equation:

$$\begin{bmatrix} {}^ox_{A_i} \\ {}^oy_{A_i} \\ {}^oz_{A_i} \end{bmatrix} = \begin{bmatrix} {}^bx_{A_i} - r_{11}^iL_i\cos\Phi_i + r_{12}^iL_i\sin\Phi_i - r_{13}^iH_i \\ {}^by_{A_i} - r_{21}^i L_i\cos\Phi_i + r_{22}^iL_i\sin\Phi_i - r_{23}^iH_i \\ {}^bz_{A_i} - r_{31}^iL_i\cos\Phi_i + r_{23}^iL_i\sin\Phi_i - r_{33}^iH_i \end{bmatrix} \tag{4.4}$$

Plug the formula 4.3 into the equation 4.4, we can get the position of the coordinate of Σ_o of $A_i = \begin{bmatrix} {}^ox_{A_i} & {}^oy_{A_i} & {}^oz_{A_i} \end{bmatrix}^T$,which is the position of robot feet in the reference frame, the calculation method we mention is the analysis of the forward kinematics of robot's swinging leg.

Conclusion

This paper analyzes the way of using the leg organization to support the ground in a concave ground environment of the six-legged robot and its walking gait, the foot type robot which imitates the movement of six-legged insect is more adaptable than the average wheeled robot. Through the kinematics calculation of the standing leg and swinging leg in the special environment, we can control the robot's move organizations better and make it more stable and efficient in walking.

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