Research on gait design of Hexapod Bionic Robot under damaged condition

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Abstract. Hexapod robot plays an important role in rescue and relief, battlefield rescue and other occasions. However, due to the influence of environment and other factors, the hexapod robot may be damaged to different degrees, which makes it unable to work normally. This paper studies the gait of hexapod robot under the condition of damage, analyzes the different damaged conditions of hexapod robot, establishes the hexapod robot model under different damaged conditions, studies the gait and stability of hexapod robot under the condition of single-leg damaged, and plans the stable gait suitable for the robot to continue to work. According to the simulation analysis, the four-legged and three-legged gait of the hexapod robot under the condition of single-foot damage which makes itself work normally is obtained. The research method in this paper can be applied to other multi-legged robots under different damage conditions, which has certain significance to improve the working life of these kinds of robots.

1. Typical gait planning of hexapod robot

Hexapod bionic robot has three-legged gait, four-legged gait, five-legged gait and other typical gait. Among them, the characteristic of three-legged gait is that the robot always has three legs in the phase of swinging, which are not adjacent to each other, while other legs are in supporting phase. The characteristic of four-legged gait is that the robot has four legs in the supporting phase at any time during the moving process, while the other non-adjacent legs are in the swinging phase. The characteristic of five-legged gait is that the robot has five legs in the supporting phase and one leg in the swinging phase at any time during the moving process.

Stability margin refers to the shortest distance from the vertical projection of the center of gravity of the multi-legged robot in the support plane to the support polygon formed by the contact point between the support leg and the support plane.

As shown in figure 1. The stability margin should be analyzed in one cycle while the damaged hexapod robot is moving. During a movement cycle, if the stability margin is always greater than 0, it means the corresponding gait can make it move normally. And at a certain time, the larger the stability margin is, the more stable the hexapod robot will be.
2. Damage analysis of the robot

2.1. Normal condition
Figure 2 shows the hexapod robot under normal conditions.

2.2. Single-leg damaged conditions
Single-leg damaged conditions are shown in Figure 3. L1, L3, R1 and R3 are equivalent, which means the damage to any foot will result in the same result. Likewise, L2 and R2 are equivalent, so there are only two cases of damage to a single foot.

3. Gait analysis of hexapod robot
Follows are parameters of the hexapod robot: The length and width of the robot body are 220mm and 120mm, with the hip joint of the middle leg of the robot body 20mm away from the front leg and back leg. The three-degree-of-freedom leg structure is adopted. Starting from the body, the length of each leg segment is set as the first leg segment is 25mm for the basal segment. The second leg segment is 140mm for the femoral segment, and the third leg segment is 130mm for the tibia segment.

The body and leg structure model of hexapod robot is shown in Figure 4.
Figure 4. Body and leg structure model of hexapod robot

With the center of gravity of the robot at the initial position as the origin, a cartesian coordinate system is constructed and the projection of the robot is cast in the coordinate system. When the robot is in the initial position, the left front, left rear, right front and right rear legs are all at an angle of 30° with the horizontal axis. The mapping of a hexapod robot in coordinates is shown in Figure 5.

Figure 5. The mapping of a hexapod robot in coordinates

3.1. Gait analysis of hexapod robot under normal conditions

3.1.1. Five-legged gait

Five legs are in the supporting phase and one leg is in the swinging phase. At this point, the gait planning diagram of the robot is shown as follows.

Figure 6. Five-legged gait planning of hexapod robot under normal conditions
As shown in figure 6, the leg marked green indicates that the leg is in swinging phase, while the leg marked black indicates that the leg is in supporting phase.

Figure 7. The stable margin polygon and the position of the center of mass.

As shown in figure 7, during the overall movement of the robot, the center of mass of the robot is always located within the stability margin polygon. According to the stability margin theory of the robot, the gait has good stability.

3.1.2. Four-legged gait

Four legs are in the supporting phase and two legs is in the swinging phase. At this point, the gait planning diagram of the robot is shown as follows:

Figure 8. Four-legged gait planning of hexapod robot under normal conditions.

Figure 9. The stable margin polygon and the position of the center of mass.
As shown in figure 9, during the overall movement of the robot, the center of mass of the robot is always located within the stability margin polygon. According to the stability margin theory of the robot, the gait has good stability.

3.1.3. Three-legged gait
Three legs are in the supporting phase and the other legs are in the swinging phase. At this point, the gait planning diagram of the robot is shown as follows:

![Figure 10. Three-legged gait planning of hexapod robot under normal conditions](image)

As shown in figure 11, during the overall movement of the robot, the center of mass of the robot is always located within the stability margin polygon. According to the stability margin theory of the robot, the gait has good stability.

3.1.4. Other conditions
In two-legged gait, gait planning is complementary to four-legged gait.

When the gait below the two-legged gait is adopted, which means that the number of legs in the supporting phase is less than two, the stability margin polygon formed is one point, and the center of gravity of the robot cannot always fall in it and cannot maintain stability, so it will not be analyzed separately.

3.2. Gait analysis of hexapod robot under the single-leg damaged condition

3.2.1. Four-legged gait under single-leg damaged condition
Four legs are in the supporting phase and one leg is in the swinging phase. At this point, the gait planning diagram of the robot is shown as follows:
As shown in figure 13. When the hexapod robot moves in a quadruped gait under the condition of single-leg damaged, and when L1 leg is in swinging phase, the center of mass of the robot falls on one side of the stability margin polygon, and the stability margin of the robot is 0, which is in a critical state. When R1 is in swinging phase, the stability margin value of the robot is also very small. That is to say, when the two legs adjacent to the damaged leg are in swinging phase, the stability of the robot is the worst, but the stability margin is not less than 0, and the robot can walk normally.

3.2.2. Three-legged gait under single-leg damaged condition
Three legs are in the supporting phase and two legs are in the swinging phase. At this point, the gait planning diagram of the robot is shown as follows:
As shown in figure 15. When the hexapod robot with single-leg damage moves in three-legged gait, and when group A (L2 and R3) and group D (R2 and L2) are in swinging phase, the center of mass of the robot falls on one side of the stability margin polygon, and the stability margin value of the robot is 0, which is critical state. When group C (R1 and R3) is in swinging phase, the stability margin value of the robot is also very small. When group B (L3 and R2) and group E (R1 and L3) are in swinging phase, the stability margin value of the robot is large and the robot is relatively stable.

4. Conclusion
For the hexapod robot under the single-leg damaged condition, when the leg adjacent to the damaged leg is in swinging phase, the stability margin value of the robot is small and the stability is not high. Under the condition of damage, the stability margin value of each state in four-legged gait and three-legged gait is greater than or equal to 0, and the robot can walk normally. Compared with four-legged gait, more states of three-legged gait are located at the critical value of stability margin 0, and the robot is prone to tipping.

For the above situation, two aspects need to be improved. First, a compensation mechanism is designed to compensate the center of mass when the above situation occurs to the robot, so that the center of mass is shifted to the stable margin polygon. The second is to reduce the duration of the above states so that the robot can transition to the next state more quickly.

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References
[1] Haitao Yu, Haibo Gao, Zongquan Deng. Enhancing adaptability with local reactive behaviors for hexapod walking robot via sensory feedback integrated central pattern generator[J]. Robotics and Autonomous Systems, 2020, 124.

[2] Gang Chen, Bo Jin, Ying Chen. Accurate and robust body position trajectory tracking of six-legged walking robots with nonsingular terminal sliding mode control method[J]. Applied Mathematical Modelling, 2020, 77(Pt 2).

[3] Wang Wei, Chu Zenan. Research on gait planning of hexapod robot [J]. Computer era, 2019(12): 8-11.
[4] Xu Shoulin, He Bin, Hu Heming. Research on Kinematics and Stability of a Bionic Wall-Climbing Hexapod Robot. [J]. Applied bionics and biomechanics, 2019, 2019.

[5] Bai Long, Hu Hao, Chen Xiaohong, Sun Yuanxi, Ma Chaoyang, Zhong Yuanhong. CPG-Based Gait Generation of the Curved-Leg Hexapod Robot with Smooth Gait Transition. [J]. Sensors (Basel, Switzerland), 2019, 19(17).