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Singularity analysis and dimensional optimization on a novel serial-parallel leg mechanism

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Abstract

A novel series-parallel hybrid mechanism is presented to overcome the limitations of serial robots and parallel robots caused by the mechanism characteristics, and using it as the leg, a serial-parallel quadruped robot is structured. Based on vector method and differential transform method, velocity Jacobian matrix of the hybrid leg mechanism is gained, and singularity of the leg is analyzed ulteriorly. In order to evaluate the kinematic dexterity of the hybrid leg, dexterity evaluation indexD_h is proposed, further more, dimensional optimization has been taken according to index D_h, and results show that, when angle between driving shaft of the hip and vertical direction is 50.5 degree and the ratio of the thigh and the calf is 0.72, index D_h is maximum, that is, the hybrid leg has best dexterity. In accordance with the results of the optimization, prototypes of the hybrid leg and the serial-parallel quadruped walking robot have been successfully trial-produced. This research helps lay a solid foundation for a series of further studies of the novel series-parallel quadruped robots.

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Keywords: series-parallel; singularity analysis; dexterity evaluation index; dimensional optimization;

1. Introduction

Considering control difficulty, manufacturing cost and stability of walking robots, quadruped robots have more advantages than both hexapod and biped robots[1,2], which leads the research of quadruped robots to higher research significance and social value in many aspects, such as exploration, mine, rescue and so on[3-5]. With people putting forward higher requirements to quadruped robots, quadruped robots with high speed, low energy consumption, onboard power sources have become research hotspot[6]. As an important part of quadruped robots, design of leg mechanism plays a decisive role in the kinematics and dynamics characteristics of the robot, which has been one of

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the key problems of research of quadruped robot with high speed and maneuverability[7].

Most of leg mechanisms of existing quadruped robotsadopt series or parallel mechanism, for instance, BigDog robot[8] designed by American Boston Dynamics Inc, HyQ robot[9] developed by Italy and Scalf robot[10] designed by Shandong University, employed serial leg mechanisms, while walking robot put forward by Zhang Cheng-jun[11] and parallel mechanical leg raised by Rong Yu and Jin Zhen-lin[12], adopted parallel leg mechanisms. Serial structure leg has simple structure, easy control, but it has high weight-load ratio and low bearing capacity[13]. On the contrary, parallel structure leg has low weight-load ratio, high bearing capacity and high stability, but it has complex structure and small workspace, which make it difficult to complete high speed obstacle avoidance and obstacle-navigation. Both serial and parallel leg mechanism have their limitation restricted by their structural characteristics.

In order to overcome the limitations of serial robots and parallel robots, a novel serial-parallel hybrid mechanism is presented. Using it as a leg, a hybrid quadruped robot is structured. Based on vector method and differential transform method, velocity Jacobian matrix of the hybrid leg mechanism is gained, and singularity of it is analyzed ulteriorly. In order to evaluate the kinematic capability of the hybrid leg, dexterity evaluation index D_h applying to hybrid mechanism is proposed. Further more, dimensional optimization has been taken according to index D_h. In accordance with the result of optimization, prototypes of the hybrid leg and the serial-parallel quadruped robot have been successfully trial-produced.

2. Mechanism description

The hybrid leg mechanism is connected by a hip joint, a thigh and a calf sequentially, and the hip joint is a 3-RRR spherical parallel mechanism of 3 rotational DOFs, as shown as Fig.1. Knee joint is driven by a linear motor instead of rotating motor, which improves the center of gravity of the leg and decrease rotational inertia imposed upon knee joint by leg mechanism. The hip joint is driven by three rotating motors distributing at three RRR branches separately. To improve reaction rate and motion stability, every driving motor is mounted beside the fixed platform of the hip. The hybrid quadruped robot is structured by four identical hybrid leg mechanisms and a carrying platform, as shown in Fig.2. Due to the hybrid leg mechanism, the quadruped robot has both big workspace and high bearing capacities simultaneously.

Fig.1. Hybrid leg mechanism

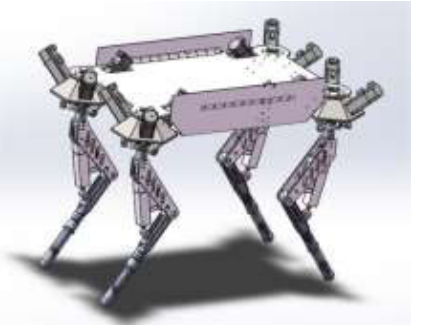

Fig.2. Serial-parallel walking quadruped robot

3. Singularity analysis

The leg is a serial-parallel mechanism, so we should analyze singularity of the hip joint firstly, then viewing the hip joint as a spherical joint, the whole leg can be equivalent to a SR mechanism, finally analyze the singularity of the SR mechanism.

3.1. Kinematic model

The hip joint is a 3-RRR spherical parallel mechanism, and its coordinate systems are built as shown in Fig.3. Fixed and moving coordinate systems $\boldsymbol{O}x_0y_0z_0$ and Oxyz are established at the rotation center $\boldsymbol{O}$ of the hip joint, while $\boldsymbol{O}x_{ij}y_{ij}z_{ij}$ represents coordinate system of rotation joint j of branch i, (i, j=1, 2, 3), and vectors $\boldsymbol{u_i}$, $\boldsymbol{v_i}$ and $\boldsymbol{w_i}$ donate the unit vector of first, second and third revolute joint of branch i respectively, and angle φ_i represents the

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