Design and Optimization of Wheel-legged Robot: Rolling-Wolf

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Abstract: Though the studies of wheel-legged robots have achieved great success, the existing ones still have defects in load distribution, structure stability and carrying capacity. For overcoming these shortcomings, a new kind of wheel-legged robot (Rolling-Wolf) is designed. It is actuated by means of ball screws and sliders, and each leg forms two stable triangle structures at any moment, which is simple but has high structure stability. The positional posture model and statics model are built and used to analyze the kinematic and mechanical properties of Rolling-Wolf. Based on these two models, important indexes for evaluating its motion performance are analyzed. According to the models and indexes, all of the structure parameters which influence the motion performance of Rolling-Wolf are optimized by the method of Archive-based Micro Genetic Algorithm (AMGA) by using Isight and Matlab software. Compared to the initial values, the maximum rotation angle of the thigh is improved by 4.17%, the maximum lifting height of the wheel is improved by 65.53%, and the maximum driving forces of the thigh and calf are decreased by 25.5% and 12.58%, respectively. The conspicuous optimization results indicate that Rolling-Wolf is much more excellent. The novel wheel-leg structure of Rolling-Wolf is efficient in promoting the load distribution, structure stability and carrying capacity of wheel-legged robot and the proposed optimization method provides a new approach for structure optimization.

Keywords: wheel-leg, multi-objective optimization, Rolling-Wolf, hybrid locomotion, robot

1 Introduction

Autonomous robots have received much attention in recent years due to their high adaptability in unstructured environments. Robots such as Nomad[1], Big-Dog[2], Sojourner[3], Work-Partner[4] and AZIMUT[5] have many potential applications, including geological investigation, space exploration, military reconnaissance, defense, et al. These high-performance mobile robots can be classified into walking, wheeled, crawling and hybrid locomotion[6]. Wheel-legged robots (WLR) have been considered as the most promising mobile robots of the next generation, for inheriting both advantages of wheeled and walking systems, i.e. the rapidity and efficient movement of wheeled robots and better obstacle overcoming performance of legged robots.

Over the last decades, various kinds of WLR have been designed, such as Chariot-II[7], ATHLETE[8], Octopus[9], Work-Partner, LegVan[10], HyTRo-I[11], NOROS-II[12] and Hylos[13]. Within these work, kinematics, dynamics, control systems, trajectory planning, gait planning, navigation systems, etc. have been widely studied. GRAND, et al[13], focused on using kinematic-based decoupling control system to guarantee the stability of Hylos robot, and this method is proved to be useful though inefficient from the point of view of the energy consumption. BESSERON, et al[14], proposed an upgrade control scheme based on GRAND’s efforts, which used artificial potential field for the on-line stability control. SPERZYŃSKI, et al[15], proposed the kinematic and dynamic models of WLR, and used them to analyze the motion performance of wheel-leg robot. SUZUMURA, et al[16], proposed a method of trajectory planning using zero-phase low pass filter to realize both fast legged and wheeled locomotion. SARTAJ, et al[17], proposed a method for gait sequence generation which is used to negotiate discontinuous terrains. XU, et al[18], analyzed the gait of NOROS(an radial symmetrical hexapod robot) based on parallel mechanisms. All of these studies are of significance for promoting the motion performance and adaptability of WLR running on rough terrains.

Though great progress has been made, there still has a long way to build a truly practical WLR which can widely adapt to the unstructured terrains. On one hand, the studies of control method, gait design, path planning, et al, are all tough issues which still need to be deeply researched; on the other hand, the development of new and specialized mechanical structures for solving the defects of the existed WLR is still a topic of ongoing research. For example, most of the previous designs, their driving motors were added to the joints directly, such as Roller-Walker[19], Go-For[20], ATHLETE[8], Octopus[9], HWLV[21], et al. This
kind of WLR has one or more defects in load distribution, structure stability, and carrying load.

Generally, there are some designs like: Hylos, LegVan, HyTRo-I, ALDURO[22], PAW Robot[23], et al. that can be considered as the attempts to solve the above structural defects. For example, Hylos robot, designed by GRAND, et al, used electric push rods to drive the movements of legs, technically solving the structure stability problem and improving its carrying load. However both of the push rods of the same leg were fixed on the body, resulting in a large non-independence between the thigh and calf. Thus, when the thigh in a different position, the same stroke of the calf driving push rod will result a different rotation angle, which is not conducive to the robot’s posture control. Robot LegVan[10], designed by GRONOWICZ, et al, who focused on the mechanical structure of WLR, has a special suspension system to reduce the number of drivers when on the mechanical structur e of WLR, has a special structure stability and carrying load. However both of the push rods of the same leg were fixed on the body, resulting in a large non-independence between the thigh and calf. Thus, when the thigh in a different position, the same stroke of the calf driving push rod will result a different rotation angle, which is not conducive to the robot’s posture control.

Robot ALDURO[22], designed by GERMANN, et al, incorporated mechanically solving the structure stability problem and also good load distribution. Robot LegVan[10], designed by GRONOWICZ, et al, who focused on the mechanical structure of WLR, has a special suspension system to reduce the number of drivers when performing the leveling and walking movement. However, LegVan still has the same defects as Hylos robot does: its control system would not be simplified. Robot HyTRo-I[11], designed by LU, et al, incorporated mechanically decoupled legs and wheels. Though this method combines both of the advantages of wheeled and legged robots, it is too complicated and redundant no matter operated in any motion modes, such as walking, rolling or hybrid motion.

For overcoming the defects of the existing WLR in load distribution, structure stability and carrying capacity, the authors of this paper designed a new kind of wheel-legged robot: Rolling-Wolf[24-29], actuated by means of ball screws and sliders, which is simple but has high structure stability and also good load distribution.

The main works of this study include motion performance analysis and structure optimization of this new robot. Firstly, the design concepts are described in section 2. Secondly, the positional posture model and static model which are used to analyze the motion performance of Rolling-Wolf are built based on the kinematic theory and the principle of virtual works, in section 3 and section 4, respectively. Thirdly, important indexes for evaluating its kinematic performance can be analyzed by the position posture model depicted in Fig. 2. The multi-objective optimization problem of Rolling-Wolf is solved numerically by the method of Archive-based Micro Genetic Algorithm(AMGA) by using Isight and MTALAB in section 6. The optimized results were analyzed and compared with the initial values. The optimized results indicate that Rolling-Wolf turns to be much more excellent. And conclusions are drawn in section 7.

2 Design Characteristics of Rolling-Wolf

The schematic diagram of Rolling-Wolf is shown in Fig. 1. The black triangle AB is the thigh and triangle DEF is the calf. Point F is the center of the wheel. Point A and D are the revolute joints of the thigh and calf, respectively. C and G are the driving sliders moving on screws DB and MN, respectively. BG, CE are connecting rods driving the thigh and calf, respectively. The spring absorber installed on CE is used to protect the wheel-leg of Rolling-Wolf, and the spring absorber works when the calf is subject to severe impacts, such as collision with an obstacle.

As shown in Fig. 1, there are mainly three advantages of this new mechanism. Firstly, there are 4 load points applied to the thigh and 3 load points applied to the calf, respectively. Therefore, the load distribution of Rolling-Wolf has been improved significantly compared to the normal ones which add their driving motors to the joints directly. Secondly, it forms two stable triangle structures(triangle ABG and DEC) at any moment, making this new mechanism much more stable and be able to carry heavy loads. Thirdly, the motions of the thing and calf are independent, which do not have the defects of Hylos and LegVan.

3 Positional Posture Analysis of Rolling-Wolf

Motion characteristics of robots such as Hylos, ALDURO and Rolling-Wolf are deeply depended on its own wheel-leg mechanisms and structure parameters. The relationship between the structure parameters and kinematic performance can be analyzed by the position posture model depicted in Fig. 2.

As shown in Fig. 2, Point V coincides with point A. \( ^vR = (V_x, V_y, V_z) \) is the coordinate system of the body. \( ^aR = (A_x, A_y, A_z) \) is the coordinate system of the thigh, where \( A_x \) is in parallel with the moving direction of slider C. \( ^bR = (D_x, D_y, D_z) \) is coordinate system of the calf. \( ^nR = (N_x, N_y, N_z) \) is a fixed coordinate system.