

Design and Motion Analysis of Wheel-leg Compound Variable

Displacement and Obstacle Surmounting Robot

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Abstract. Aiming at the characteristics of unstructured environment, this paper proposes a new type of wheel-leg compound mobile robot suitable for unstructured environment. This innovation is that the robot adopts the wheel-leg compound configuration and sliding structure of the fuselage, and it can carry out the load to the heightened surface with large height difference through the deformation of the body without the need of auxiliary. In the process of crossing the barrier, the robot can keep the load plane parallel to the ground and the robot has a strong ability to adapt to the environment and the ability to obstruct the obstacle. The performance of the mobile robot under unstructured environment, including walking on slope, surmounting obstacles, striding ditches, stepping up and down ladders etc., is analyzed.

Introduction

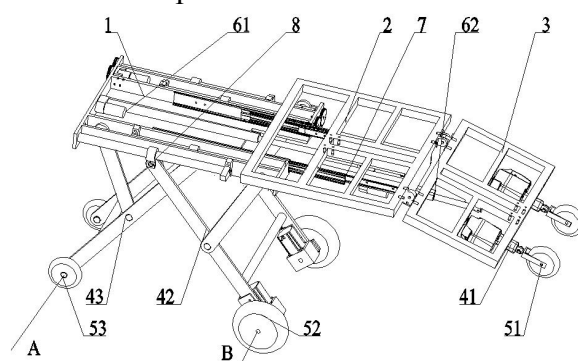
Mobile robots are divided into three major categories: wheeled, tracked and legged, depending on the mode of motion [1,2]. With the advancement of science and technology, mobile robot makes the walking mechanism has been a new development through the combination of different sports. Such as: the wheel-legged robot, track-legged robot, wheel-tracked robot, wheel-track-legged robot and so on, this type of robot called hybrid robot.

Wheeled mobile robot has the characteristics of flexible, stable operation, fast speed and large load [3,4], but its adaptability to terrain and obstacle negotiation is limited. In contrast, legged mobile robots have good terrain adaptability and obstacle surmounting capability, but their mobile performance is poor and their configuration is complex. Wheel-legged mobile robot combines the advantages of wheeled robot and legged robot so that the robot has a good mobile performance at the same time also has a strong barrier capability. However, the performance of the wheel-legged mobile robot is far from the above-mentioned movement characteristics at the present, how can the wheel-legged robots play their proper level of exercise, so that the perfect combination of wheeled robots and legged robots has become the field of research focus. Based on this, domestic and foreign scholars have made a lot of research on wheel-legged mobile robots. Boston's Handle robot movement is powerful, and the wheeled robot has a strong bounce ability. But it has a relatively high degree of freedom, control complex, high cost, and the robot static balance instability has security risks. The robot has no climbing step function, so it will take some time to test its practical value. The United States JPL laboratory developed Rocky series wheel-legged robots [5,6], the robot through the connecting rod will be linked to each wheel-leg, and increases the ability of coordinating and surmounting obstacles among each wheel-leg. Using it in the Mars exploration program, the robot has shorter legs, and can only move over the gently undulating barrier, and can not be applied to stepped terrain. "Roller-walker" robot was developed by Japan's Tokyo Institute of Technology and the robot increases a degree of freedom hinge rotating wheel at the bottom of the leg portion [7]. It can switch between wheel and leg according to the different terrain. By cleverly combining the

advantages of wheeled robots and legged robots, the robot's environmental adaptability is enhanced. But the robot has poor load capacity and more leg joints, which makes it more difficult to control. A robot with 6 legs which can adapt all terrain was designed in the Key Laboratory of robotics, Shenyang Institute of automation, Chinese Academy of sciences. The six driving wheels of the robot are connected to the vehicle body through a passive compliant mechanism, thus reducing the complexity of the mechanism. But because of the local elastic deformation of the leg, the load plane of the robot can not keep parallel with the ground. In order to solve the above problems, this paper mainly studies a kind of wheel-legged composite variable displacement and obstacle surmounting robot suitable for unstructured environment. The robot adopts the wheel-leg compound configuration and sliding structure of the fuselage, and it can carry out the load to the heightened surface with large height difference through the deformation of the body without the need of auxiliary. The performance of the mobile robot under unstructured environment, including walking on slope, Surmounting obstacles, striding ditches, stepping up and down ladders etc., is analyzed.

Mechanism configuration of the robot

As shown in figure 1, the robot adopts the wheel-leg compound configuration and sliding structure of the fuselage. The whole robot is divided into two parts. The upper half of the fuselage is defined as the upper body, and the lower half of the fuselage is the lower body. In the figure, part 4 (including 41, 42, 43) is the leg of the wheel-legged composite structure, the legs 41 and 42 can adjust their height to adapt to different height ground, the leg 43 can be to contact the ground through their own elongation and shortening. The part 5 (including 51, 52, 53) in the figure is the moving wheel part of the wheel-leg composite structure, the front wheels 51 and the rear wheels 53 are driven wheels, and the middle wheels 52 are the driving wheels. The push rod 61 and the slide 7 form a sliding mechanism together, and the push rod 61 is used for pushing the upper body to slide relative to the lower body on the slide rail 7. The push rod of support plate of front leg 62 is used for driving the support plate of front leg 3 to rotate relative to the body. The part 8 is the ball screw mechanism, and it makes up the crank-slider mechanism with the legs 4. The crank-slider mechanism is used to drive the wheel to lift up and down relative to the body. The mobile robot has ordinary mobile robot functions, including walking on slope, Surmounting obstacles, striding ditches, stepping up and down ladders etc., but also through its deformation mechanism, shapes and sizes of the volume of the robot itself obviously changes, and obstacle performance is improved.



Note: 1 lower body; 2 upper body; 3 support plate of front leg; 41 front leg; 42 middle leg; 43 rear leg; 51 front wheel; 52 middle wheel; 53 rear wheel; 61 push rod between lower body and upper body; 62 push rod of support plate of front leg; 7 slide; 8 ball screw mechanism; A rotation axis of rear wheel; B rotation axis of middle wheel

Fig. 1 Sketch map of robot structure

Performance analysis of mobile robot

Performance analysis of mobile robot in typical terrain. The unstructured environment can be viewed as a combination of complex three-dimensional terrain that includes straight-line walking,

turning, striding ditches, stepping up and down ladders and other terrain that can be considered as a combination of three typical terrain, including slope, up the steps, down the steps.

Walking on slope. When the robot is walking on slope, the mobile robot innovation lies in the middle and rear legs can change to adjust the middle wheel and rear wheel rotation axis in the vertical position through their own deformation, so the robot load plane in slope walking process can still maintain the level, with a strong slope walking ability. When the mobile robot travels on a slope with an angle, it is necessary to study the maximum angle of its uphill. This angle is only related to the robot's own posture. The following is the analysis of the relationship between the ascent angle of the robot and its own mechanism. A simplified two-dimensional model of the robot leg and lower body is shown in figure 2. When the robot walks along the slope angle θ of the slope, the robot through the adaptive wheel-legged to adjust their attitude to keep the body parallel to the ground and the slope angle θ is the attitude angle θ that the robot itself can adjust. At this point, the robot's attitude angle θ is the angle formed between the middle wheel hub and the rear wheel hub. In the fuselage on the right side of the establishment of the base coordinate system, the robot articulation joints and wheel coordinates are shown in Figure 2.

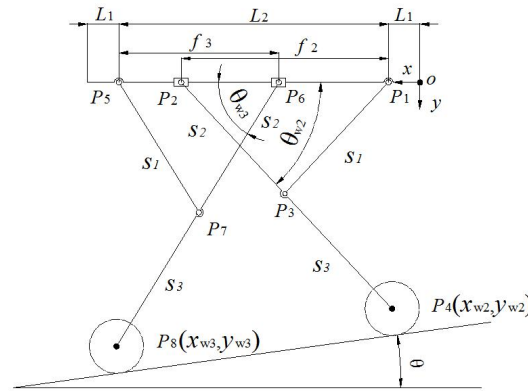


Fig.2 Geometric relation analysis between robot climbing angle and its mechanism

Note: xoy is the base coordinate system; P_1, P_3, P_5, P_7 are the joints of wheel-legged and wheel-legged internal hinge point coordinates; P_2 and P_6 are hinge points of wheel-legged and screw; coordinates $P_4(x_{w2}, y_{w2})$ and $P_8(x_{w3}, y_{w3})$ are the middle wheel, rear wheel center coordinates.

The coordinates of the middle wheel center $P_4(x_{w2}, y_{w2})$ and the rear wheel center $P_8(x_{w3}, y_{w3})$ are obtained from the plane geometry relation:

$$\begin{cases} x_{w2} = L_1 + L_2 - f_2 + (s_2 + s_3) \cos \theta_{w2} \\ y_{w2} = (s_2 + s_3) \sin \theta_{w2}. \end{cases} \quad (1)$$

$$\begin{cases} x_{w3} = L_1 + f_3 - (s_2 + s_3) \cos \theta_{w3} \\ y_{w3} = (s_2 + s_3) \sin \theta_{w3}. \end{cases} \quad (2)$$

Note: L_1 is the distance between the left and right sides of the fuselage and the fuselage; L_2 is the distance between the left and right hinge points of the fuselage; s_1 is the length of the short legs of the wheel-legs; s_2 is the length of the upper part of the length of the long leg P_2P_3 and P_6P_7 ; s_3 is the length of the lower part of the length of the long leg P_3P_4 and P_7P_8 ; f_2 is the screw feed of the middle wheel-leg; f_3 is the screw feed of the rear wheel-leg, θ_{w2}, θ_{w3} are the swing angles of the middle legs, rear legs.

The attitude angle of the robot is the angle formed by the line connecting the middle wheel center and the rear wheel wheel and the ground.

$$\begin{aligned} \theta &= \arctan \left(\frac{y_{w2} - y_{w3}}{x_{w2} - x_{w3}} \right) \\ &= \arctan \left(\frac{(s_2 + s_3)(\sin \theta_{w2} - \sin \theta_{w3})}{L_2 - f_2 - f_3 + (s_2 + s_3)(\cos \theta_{w2} + \cos \theta_{w3})} \right). \end{aligned} \quad (3)$$

By formula (3), the maximum attitude angle of motion of the robot can be obtained when the robot is walking on slope, so that the maximum slope angle of the robot can be known. Robot attitude angle is positive and negative. When the attitude angle is positive, the robot is walking forward, this time the robot is walking on slope from the x -axis negative; When the attitude angle is negative, the conclusion is opposite to the previous one.

Climbing up the step. By using the structure characteristics of the wheel-legged moving mechanism and the slip mechanism, the posture of the mobile robot can be coordinated and controlled, and the step with a certain height can be achieved through self deformation and displacement.

The process of the mobile robot is shown in Figure 3. The robot before the barrier will be adjusted as shown in Figure 3 (a). In Fig. 3(b), the robot lifts the front wheel-leg and the robot moves close to the obstacle until the robot middle wheel approaches the edge of the step surface. In Fig. 3 (c), the front leg is extended to decrease the front wheel contact with the step surface. In Fig. 3 (d), the upper body slides forward with respect to the lower body with the slip mechanism, until the center of gravity of the robot is located in front of the rotating axis A. In Fig. 3 (e) the middle wheel rises above the surface of the step. Figure 3 (f), the robot slip mechanism retracts so that the middle wheel and the rear wheel move forward until the rotation axis A moves to the front of the upper body. The action is achieved by preventing the front wheel from being rolled backward by one-way bearings. In Figure 3 (g), the middle wheels are lowered until they are in contact with the upper surface of the step. Fig. 3 (h), the upper body slides forward again relative to the rotation axis A of the middle wheel so that the center of gravity of the upper body is moved again to the front of the rotating axis A. Fig. 3 (i), the rear leg retracts and the rear wheel is raised to the height above the step. Fig. 3(J), the rear wheel falls in contact with the upper surface of the step, and the slip mechanism retracts, so that the upper body moves backward relative to the rotating axis A to position the center of gravity of the upper body between the middle wheel and the rear wheel. At this point, the robot climbed up the steps.

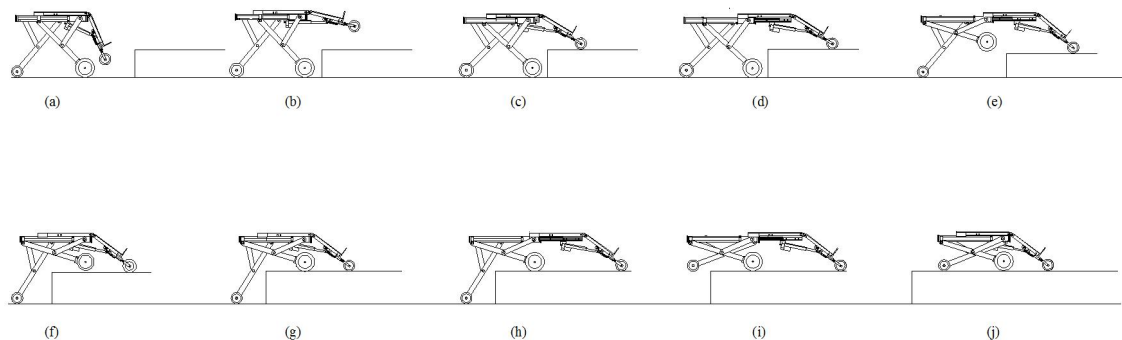


Fig.3 schematic diagram of climbing up the step

The obstacle height of the robot is an important index for the performance of the robot, and the following is the key analysis of the height of the robot. The obstacle height H of the mobile robot is related to the robot climbing process, the most important of which is Figure 3 (c) and Fig. 3(e) of the process. Figure 3 (c) shows the highest height that the front wheel can reach by the obstacle. Figure 3 (e) shows the highest height that the middle wheel can reach across the obstacle. Build the coordinate system as shown in figure 4.

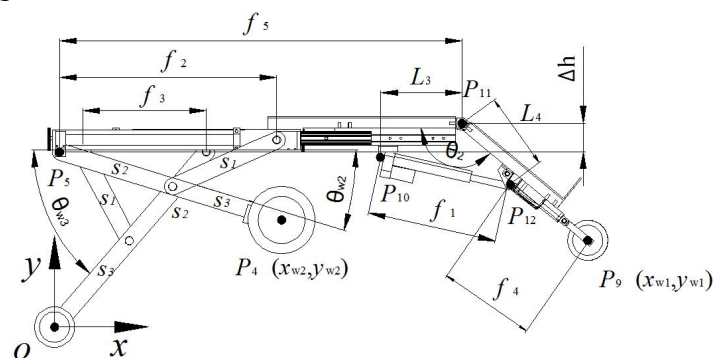


Fig. 4 height analysis of robot obstacle crossing

Note: xoy is the base coordinate system; P_4, P_5 are annotated with figure 2; P_9 is the coordinate of the center of the front wheel; coordinates P_{10} is the hinge point that connects push rod of support plate of front leg and upper body. P_{11} is the hinge point that connects support plate of front leg and upper body. P_{12} is the hinge point that connects push rod of support plate of front leg and support plate of front leg.

To achieve surmounting obstacles the robot needs to meet the following two conditions: 1) the front wheel catches the obstacle; 2) the middle wheel is raised above the obstacle. The y axes of center of front wheel y_{w1} and rear wheel y_{w2} need to meet two conditions:

$$\begin{cases} H \leq y_{w1} \\ H \leq y_{w2} \end{cases} \quad (4)$$

That is the obstacle height H of the mobile robot is $H = \min(y_{w1}, y_{w2})$.

Climbing down the step. The process of climbing down the step is approximately the same as the process of climbing up the step. The robot first moves the front leg away from the obstacle, and then slides the upper body of the robot forward by means of a slip mechanism. The front wheel touches the ground. Then the slip mechanism drives the lower body of the robot forward. The middle wheel-leg is lowered to touch the ground. The robot moves forward until the rear leg leaves the upper surface of the step. The rear wheel-leg touches the ground and finally the lower body slides forward to make the robot achieve self-recovery.

Analysis on the performance of mobile robot in combined terrain

There are many combinations, among which the ladder and trench are the two most typical. Crossing a trench is equivalent to a combination of the robot first steps and then the lower steps, and the ladder can be regarded as a combination of a plurality of upper steps. With regard to the length of the article, the following analysis focuses on the performance of the trench terrain.

Analysis on the performance of mobile robot in trench terrain. The striding ditches process of robot is shown in figure 5. The steps of robot are described in detail before, and the process of striding ditches is the same as that of the upper step. Only processes are different from the timing of action, here is no longer the details of the robot striding ditches process.

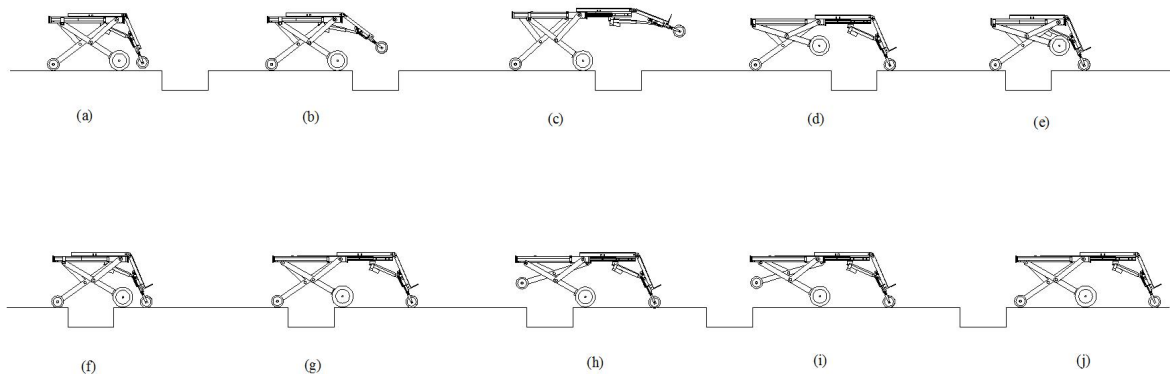


Fig.5 schematic diagram of striding ditches process

The width of the robot is the important indicator of the striding ditches performance of the robot, and the following is the key analysis of the width of the striding ditches. Through the expansion of the body, robot can cross the trenches with a certain width, so the robot geometry analysis is the key to study the striding ditches performance of the robot. In Figure 5 (d), when the upper half of the robot is used for obstacle climbing, the horizontal distance between the front wheel center of the robot and the center of the middle wheel should be greater than the width of the ditch. In Figure 5 (g), the horizontal distance between the middle wheel center and the rear wheel center of the robot should be greater than the width of the ditch when the lower body of the robot is used for obstacle climbing. The width of the ditch shall satisfy the following two conditions:

$$\begin{cases} L \leq L_1 \\ L \leq L_2 \end{cases} \quad (5)$$

Note: The L_1 is the horizontal distance between the front wheel center and the middle wheel center, and the L_2 is the horizontal distance between the middle wheel center and the rear wheel center.

Conclusions

This paper proposes a new type of wheel-leg compound moving robot suitable for unstructured environment. The performance of the mobile robot under unstructured environment, including walking on slope, surmounting obstacles, striding ditches, stepping up and down ladders etc., is analyzed from the aspects of geometric kinematics. The feasibility of this new structure and the performance of the obstacle are verified, which provide the theoretical basis for the production and debugging of the prototype.

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