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Designing and Analyzing For a Bar Linkage Obstacle-Surmounting Robot with the Same Phase in all the Wheels

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Designing and Analyzing For a Bar Linkage Obstacle-Surmounting Robot with the Same Phase in all the Wheels

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Abstract. In order to improve the obstacle-surmounting capability of robots in complex, we propose a new bar linkage type obstacle-surmounting robot with the same phase in all the wheels(BOSWbot). The robot relies on its special mechanism which all the wheels in the same phase to overcome the "singular point" problem of the single-bar over-obstacle robot. The torque of the different motors is integrated to improve the running velocity. In addition, we research a new type of wheel which is made of different materials. The robot uses the different friction in wheel surface to solve the turning problem. Finally, the way to travel of the bar linkage obstacle-surmounting robot makes it switch to the obstacle mode automatically. Then the robots complete the process of climbing obstacle.

1. Introduction

In the endless exploration of human unknown world, especially in complex operating environment, the characteristics of mobile robot such as flexibility, efficiency and adaptability obviously occupy a greater advantage. This paper mainly studies the obstacle detection robot used in post-disaster high-rise buildings or complex terrains such as fire, mine disaster and earthquake [1]. Obstacle-surmounting robots are required to have strong terrain adaptability because of their work in different environments. Therefore, there is an urgent need to study a mobile robot that takes into account both of the walking efficiency and obstacle-surmounting capability.

However, the traditional mobile robots have both of advantages and disadvantages in walking and obstacle crossing. The wheeled robot has high stability, simple structure but poor obstacle-navigation. The obstacle-surmounting ability of legged robot enhance obviously, but it has high-degree of freedom, complex structure and weak stability. Although the tracked robot can operate in many kinds of topography, it cause much of damage to the surface when turning because of the structure of track. Therefore, mobile robots which can move quickly and steadily in unstructured terrains still have much space for development in the robot field [2].

We propose a bar linkage obstacle-surmounting robot with the same phase in all the wheels in this paper which focus on the good adaptability in non-regular terrain and stable high-speed and more efficient capability of driving. In addition, the robot has the certain obstacle-avoiding, obstacle-surmounting and more wear-resistant ability [3]. We adopt the driving mode of the same phase in all the wheels to maximize the walking efficiency in the structured environment. In the unstructured environment, the special structure of the bar linkage can take the initiative to switch over the obstacle mode and improve the obstacle-surmounting ability. Hence the new design is very suitable for the field of robot detection [4, 5].



2. Robot Structure

2.1. Mechanical structure

The BOSWbot is a novel structure which is based on both sides of the wheels to add the bars, sharing a single axis on the right and left, and connecting the front and rear axes by a transmission device. It aims to have all the wheels in the same phase to achieve the driving mode of the same phase in all the wheels. As shown in Figure 1, the BOSWbot is comprised of two bars (L1, L2), four active wheels (R1, R2, R3, R4), two driveshafts (S1, S2) and four motors (D1, D2, D3, D4).

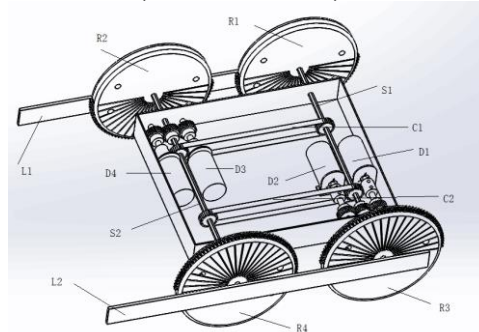


Figure 1. A Bar Linkage Structure with the Same Phase in all the Wheels

The connecting rods L1, L2 are respectively connected with the active wheels R1, R2 and R3, R4. The positioning wheels are respectively arranged on the active wheels and the bar linkage. The active wheels are connected with the obstacle-surmounting bars through the positioning holes. The position of positioning holes in active wheels should be as close as possible to the edge of the wheels, each positioning hole has the same distance to the center of the circle. The driveshafts S1 and S2 are respectively connected with R1, R3 and R2, R4, and the chains C1 and C2 are connected with S1 and S2 on both sides of the robot and keep symmetrical; the motors D1 and D2 drive the driveshaft S1, D3 and D4 to drive the driveshaft S2.

2.2. Eliminate singularities

In the movement, when the connecting rod and the two axes at the same level, ordinary single-link obstacle-surmounting robot prone to interference movement and stuck, known as the "singularity" phenomenon, resulting in the robot can not travel normally. The same phase in all the wheels system proposed in this paper solves the "singularity" problem very effectively.

For obstacle-surmounting robots, the connecting rods on both sides are all rigid structures, which do not produce the telescopic squeezing phenomenon like the elastic structure. Since the "singularity" phenomenon only occurs in the state which the axis of the obstacle connecting rod and the active wheels are in the same horizontal line. Therefore, in addition to this state point, in any other state of motion, the points where the positioning hole of connecting rod have an interaction force with each other and will drive the obstacle-bar to continue forward or backward rotation, that is, always in the same direction of movement, so it will not occur the "singularity" problem when connecting rod misalign. Similarly, when the obstacle-bars are rotated to the same horizontal line as the axis of the active wheels, because the robot chain connect to the two driveshafts by the conveyor, it can make the connecting rod with the two active wheels to maintain the same phase, to avoid the connecting rod stuck phenomenon.

2.3. The turning problems of the same phase in all the wheels

Although the structure of the same phase in all the wheels solves the "singularity" phenomenon, it also brings about the turning problems when the robot is moving, so we designed a new type of wheel to solve this problem. As shown in Figure 2, the wheel consists of two parts of the same size of material. The one part is the elastic material (such as plastic). The outer ring is smooth and the friction coefficient is μ_1 ; the other part is the rigid material (such as metal alloy). The outer ring is rough and the friction coefficient is μ_2 . The coefficient of friction of smooth outer ring with elastic material is smaller than

the rough outer ring with rigid material. The coefficient of friction makes the difference of static friction force during the movement of the wheel. According to the difference of reaction time, we can draw that the rigid material reaction time is longer than the elastic material reaction time.

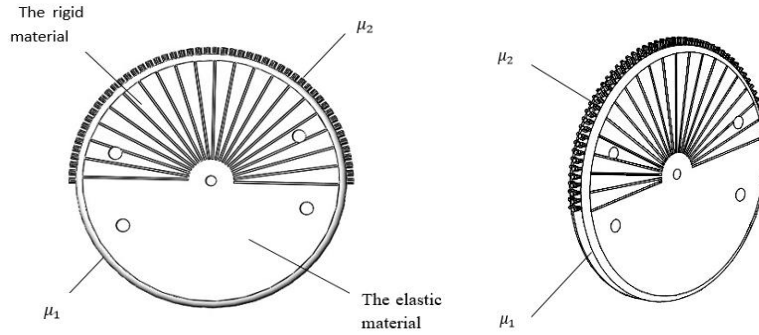


Figure 2. Action Wheels Structure Diagram

In normal state due to the lower acceleration absolute, although the friction generated on both sides are different, the reaction time between the rigid material and elastic material are different and it does not exceed the static friction limit. Therefore, it is not enough to slip and the robot moves in a straight line.

When the absolute value of acceleration is too large, all the wheels on both sides of the robot break through the friction, then the robot slips. The friction on the side of the small friction coefficient is small, so that the large friction side force deflects to the small friction side. Due to rigid material reaction time is longer than the elastic material reaction time, prompting the side of a large friction force to the smaller side of the smaller deflection.

When the absolute value of acceleration is moderate, it is analyzed from acceleration and phase respectively. The movement of the robot in acceleration state as shown in Figure 3.

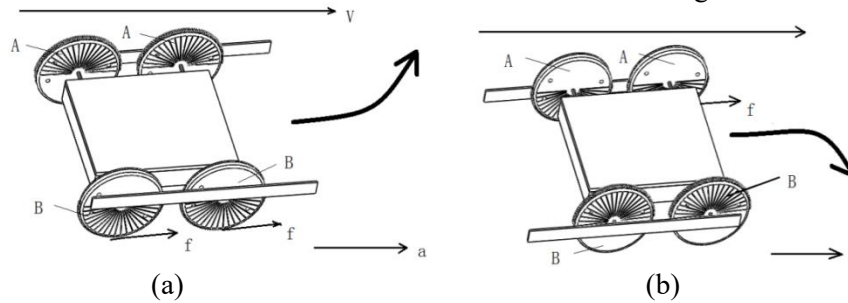


Figure 3. Accelerated movement Diagram

When the robot accelerates in the movement, the acceleration direction is positive. At this time, the sliding friction force provides the combined force of movement. The active wheels (A, B) slip. We analyze dynamics of A and B wheels as shown in the following equation:

$$\begin{cases} f_A = m \cdot a_A \\ f_B = m \cdot a_B \end{cases} \quad (1)$$

Where f_A is the sliding friction in A wheel, f_B is the sliding friction in B wheel, a_A is the acceleration of A wheel and a_B is the acceleration of B wheel.

Because of the mechanism of all-wheel in-phase, the angular velocity of the four wheels is the same. Due to the wheels on both sides are complementary in phase and the materials of the ground contact are different, the frictional are also different. The model is established for A and B by the following:

$$\begin{cases} S_A = v_0 \cdot t + a_A \cdot t^2 \\ S_B = v_0 \cdot t + a_B \cdot t^2 \\ v_0 = \omega \cdot r \end{cases} \quad (2)$$

Where S_A , S_B are the movement displacement at the same time for both sides of the wheels, v_0 is the initial velocity, then the robot's phase is not changed. Hence the four wheels have the same velocity.

When the robot's phase changes, the instantaneous velocity of the wheel also changes. When the robot moves to the position shown in Figure 3 (a), the smooth outer ring of wheel A and the rough outer ring of wheel B are in contact with the ground. The friction force of A wheel is smaller than the friction force of B wheel as shown in the following:

$$f_A < f_B \quad (3)$$

Then for the acceleration can be given by

$$a_A < a_B \quad (4)$$

By the equation (2) and (4) can be obtained by

$$S_A < S_B \quad (5)$$

Therefore, at the same time, the displacement of the wheel on the side B is larger. Furthermore, the reaction time of the wheel B is longer than the reaction time of the A wheel. It is precisely because of these two factors make the robot deflection to the left.

When the robot moves to the position shown in Figure 3 (b), the rough outer ring of wheel A and the smooth outer ring of wheel B are in contact with the ground. The friction force of A wheel is greater than the friction force of B wheel as shown in the following:

$$f_A > f_B \quad (6)$$

Then for the acceleration can be given by

$$a_A > a_B \quad (7)$$

By the equation (2) and (7) can be obtained by

$$S_A > S_B \quad (8)$$

Therefore, at the same time, the displacement of the wheel on the side A is larger. Furthermore, the reaction time of the wheel A is longer than the reaction time of the B wheel. It is precisely because of these two factors make the robot deflection to the right.

The movement of the robot in deceleration state as shown in Figure 4.

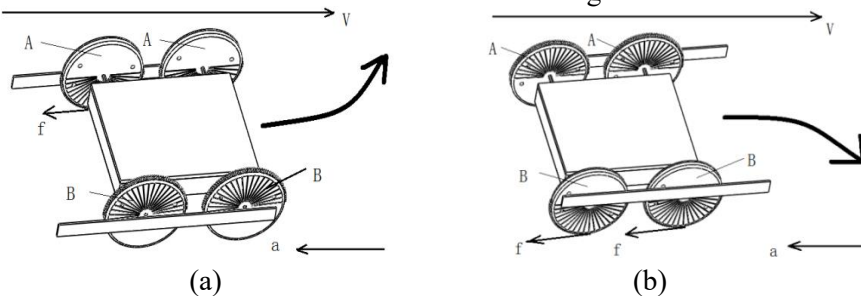


Figure 4. Deceleration movement Diagram

When the robot decelerates in the movement, the acceleration direction is negative. At this time, the reverse sliding friction force provides the combined force of movement. The active wheels(A, B) slip. We analyze dynamics of A and B wheels as shown in the following equation:

$$\begin{cases} -f_A = m \cdot -a_A \\ -f_B = m \cdot -a_B \end{cases} \quad (9)$$

Due to the wheels on both sides are complementary in phase and the frictional forces are also different. The kinematics model is established for A and B by the following:

$$\begin{cases} S_A = v_0 \cdot t - a_A \cdot t^2 \\ S_B = v_0 \cdot t - a_B \cdot t^2 \\ v_0 = \omega \cdot r \end{cases} \quad (10)$$

When the robot moves to the position shown in Figure 4 (a), the rough outer ring of wheel A and the smooth outer ring of wheel B are in contact with the ground. The friction force of A wheel is larger than B wheel. Therefore, at the same time, the displacement of the wheel on the side B is larger. Furthermore, the reaction time of the wheel A is longer than the reaction time of the B wheel. It is precisely because of these two factors make the robot deflection to the left.

When the robot moves to the position shown in Figure 4 (b), the rough outer ring of wheel B and the smooth outer ring of wheel are in contact with the ground. The friction force of B wheel is larger than

A wheel. Therefore, at the same time, the displacement of the wheel on the side A is larger. Furthermore, the reaction time of the wheel A is smaller than the reaction time of the B wheel. It is precisely because of these two factors make the robot deflection to the right.

3. Robot Drive Method

3.1. Flat mode

In this paper, the working process of obstacle crossing robots is divided into two parts, one is the analysis of the march on the flat road and the other is the obstacle analysis under the unstructured terrains. Under the flat road, the traveling wheel travels in the form of a circular wheel. The traveling efficiency is the same as that of a wheel with the same diameter. The obstacle-crossing link cannot touch the ground while traveling, but only rotates around the power shaft, not only does not affect the normal progress, but also to promote the movement of the robot. All-wheel drive mechanism in phase will be generated by different motor torque through the conveyor integration, so that robots in the walking process to obtain more robust power, without the need for motor division of labor, making the driving force to maximize the most effective and bring the most barrier ability and walking efficiency. As shown in Figure 5.

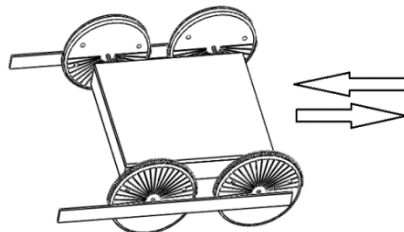


Figure 5. Robot Movement in Flat Road

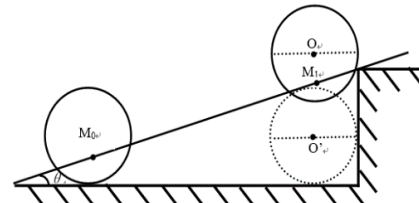


Figure 6. Obstacle Mode Switching Automatically

3.2. Obstacle mode

When walking under irregular ground, BOSWbot mainly move forward by linkage of wheels and connecting rods, and actively switched from flat mode to obstacle mode, as shown in Figure 6.

The robot crosses over the barrier automatically is shown as in Figure 6, the support point of the wheel is M, the driving point of the electrical machinery is O. When the robot encounters an obstacle during driving, the bar linkage first hovers over the obstacle. With the drive of the power shaft, the bar linkage on the obstacle plays the role of supporting the whole body. The wheel rotates around the support point M and the motor drives O point trajectory of OO', so the maximum obstacle height is

$$H = 2e + R \quad (11)$$

e is the eccentricity, that is, the distance from point O to point M. When the positioning hole is maximally close to the edge of the wheel, e has a maximum value. The obstacle height reaches the ideal maximum to be $3R$. In this case, the angle between the connecting rod and the ground is θ .

$$\theta = \arctg((2R - e)/R) \quad (12)$$

The distance between two wheels is L:

$$L = 3R / \sin \theta - 2R \quad (13)$$

The length of the connecting rod protruding at both ends is S, as shown in (14).

$$S = R * \cos 2\theta \quad (14)$$

Then the robot actively switch over the obstacle mode to cross the obstacle of not more than $3R$ height, the following conditions should be met.

$$\begin{cases} \theta = \arctg((2R - e)/R) \\ L = 3R / \sin \theta - 2R \\ S = R * \cos 2\theta \end{cases} \quad (15)$$

The obstacle-surmounting bar is lowered as the wheel continues to drive until the end of rear touches the ground, preparing for the next obstacle-surmounting, which is shown in Figure 7(a) and (b). The wheel near the obstacle revolves around the wheels and the obstacle crossing point M, and the supporting

thing is the obstacle crossing bar. The other wheels move forward with the drive shaft, lifting the body up. At this point the front wheel has crossed the obstacle. If the road ahead of the obstacle is enough spacious, as shown in Figure 7(c) below, as the power axis continues to drive, the fuselage will ride on obstacles and the obstacle connecting rod will start to move with the drive of the power axis. At this time, the whole body plays a supporting role, as shown in Figure 7(d). Due to the support function of the fuselage, the power axis continues to drive the wheel to rotate until the obstacle-surmounting bar re-hovers over the obstacle to drive the entire body forward as a supporter, as shown in Figure 7(e). Finally, as the power axis continues to rotate, the fuselage will ride on obstacles once again, so that the rear wheel can rotate over the obstacles around the M-point. In addition, the body is up and the entire body surmount the obstacle in security, as shown in Figure 7(f) below.

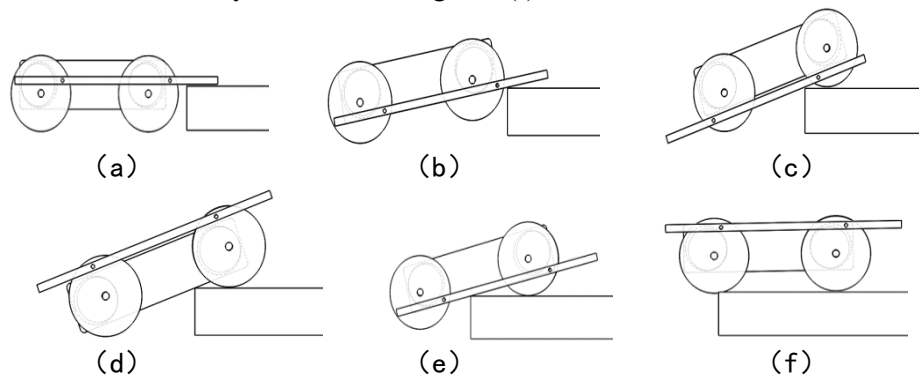
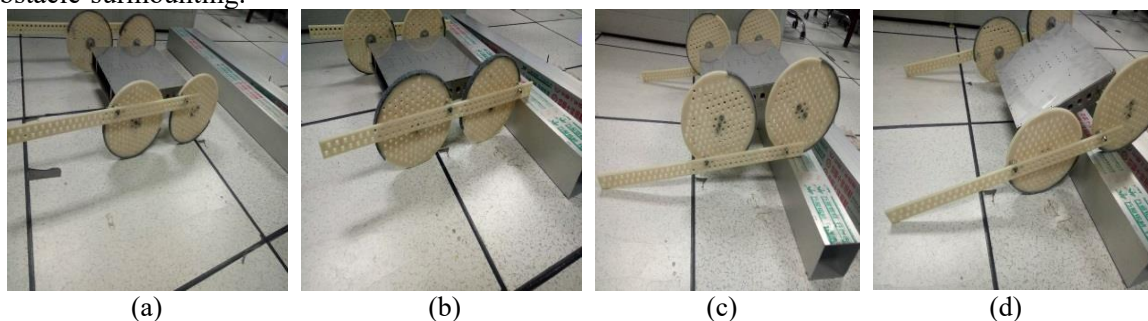


Figure 7. Robot Climbing Obstacle

During the obstacle-surmounting process, the mobile robot gains full torque when any one of the wheels has grip, which is good for leaping over the obstacle. When some of the wheels run to an invalid phase, the driving force generated by the driving motor is still provided to other wheels, keeping sufficient driving force and the stability of the body. Therefore, the driving mechanism of the same phase in all the wheels enhances the ability of the robot to surmount the obstacle.

4. Experiment result

To verify the obstacle crossing principle of the BOSWbot robot and test the efficiency of walking, a series of experiments were carried out. In the experiment, four batteries(MCOBEAM / 3400Mah / 3.7V) are the power of the BOSWbot robot. MCU is Arduino nano V3.0. The motor drive module uses TSK-BTN7971.Two motors are double out axis DC motor(34JSX-31zy). The size of the BOSWbot used in this experiment was 310mm by 290mm by 160mm for the length, width and high respectively. The radius of wheels is 110mm and the distance from the front wheel to the rear wheel is 230mm. The bar linkage length is 600mm, height 175cm from the ground. Figure 8 shows the sequence of movements for obstacle-surmounting.



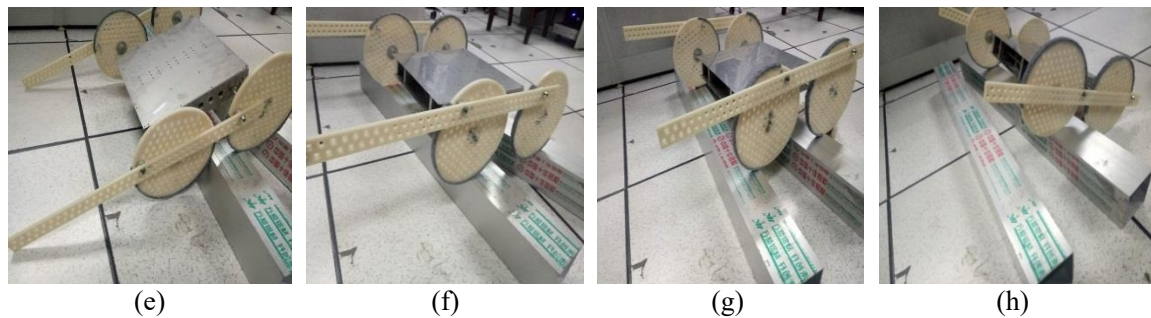


Figure 8. Robot Climbing Obstacle Experiment

5. Conclusion

In this paper, we propose a new bar linkage type obstacle-surmounting robot with the same phase in all the wheels, which is based on the all-wheel-in-phase and adopts the combination of the connecting rod and the round wheel to drive the robot. The purpose is to provide an obstacle-obsessed mechanism that takes into account the movement efficiency under regular terrain and the obstacle-free capability under irregular terrain, and solves the problems such as obstacle-crossing control complex, low movement efficiency, single-pole "singularities" and other issues, including the following points:

- Use all-wheel-in-phase mechanism to solve singular point problem of single-link obstacle
- Solve the turning problem by using different types of wheel material differences and friction forces
- Link rod to promote the wheels together and effectively bear the weight, so as to maximize the walking efficiency
- When the barrier is crossed, the robot automatically switches between the connecting rod and the wheel to make the process more efficient and reliable

The robot has the advantages of high running efficiency, strong obstacle capability, good cornering performance, small size, light weight and simple structure. The structure is easy to implement and it can be widely used in various environments. In addition, it improves the walking efficiency and obstacle ability so that it is suitable for the field of robot detection.

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