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Self-lock Characteristic of the Omni-directional Mobile Robot Based on Single Row Alternate Wheel

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Abstract: While researches on the single row alternate wheel and its mobile robot are not rarely seen, this paper offers a creative way different from past studies to analyze their self-lock characteristic by means of friction analysis. In the first stage, we analyze the structure of the single row alternate wheel. Statistics demonstrate when the single wheel is locked, it mainly creates three types of fiction: the sliding fiction along the radial direction of the wheel, and the rolling and bearing fiction along the axial direction. Experiments are designed to measure the friction coefficients. Next, we introduce the self-lock characteristic of the single row alternate wheel based on the frictions measured above. Finally, we derive a mathematical model to calculate the force on the self-locked mobile robot. Experiments are designed to test the characteristic of the mobile robot on different materials like paper and carpet, which validate the mathematical model. The results of this study contribute to a more comprehensive evaluation of various types of motion characteristics of the omni-directional wheels.

1. Introduction

The mobile robot based on omni-directional wheel is simply structured and easy to make omni-directional movements [1] [2]. The Omni-directional wheel can be divided into two categories—the Mecanum wheel and the alternate wheel—according to the degree of the angle between the roller axis and the hub axis.

In recent years, researches focused on the mobile robot based on the omni-directional wheel have been conducted both at home and abroad, and some new structures for it are also created. L. Gracia et al. derived the kinematic model for wheel slippage problems by means of successive approximation to robot dynamics [3] [4]. Mori et al. designed a new structure for the wheel drive to avoid wheel slippage, including the driving and the turning part [5]. K. Nagatan et al. gave out the fusion odometry and the orientation calculation algorithm concerning the wheel slippage problem [6]. Jondae Jung et al. proposed a fuzzy-logic-assisted interacting multiple model framework to detect and compensate for wheel slip [7]. Saha et al. established the dynamic model of a twelve wheeled mobile robot using a ‘slip’-‘friction coefficient’ relationship [8].

2. Self-lock characteristic of the alternate wheel

When the wheel is rolling, the contact points between the wheel and the ground are different. For the convenience of the following experiments, contact points between the wheels and the ground are all taken as point A, that is, the point at the center of the bigger roller.

In order to achieve the self-lock characteristics of the robot in respective directions, we change the angle ϕ between X_0OY_0 and X_MOY_M. The relationships between θ and ϕ when the robot starts to move on the slope are shown in Fig.1 and Fig.2.

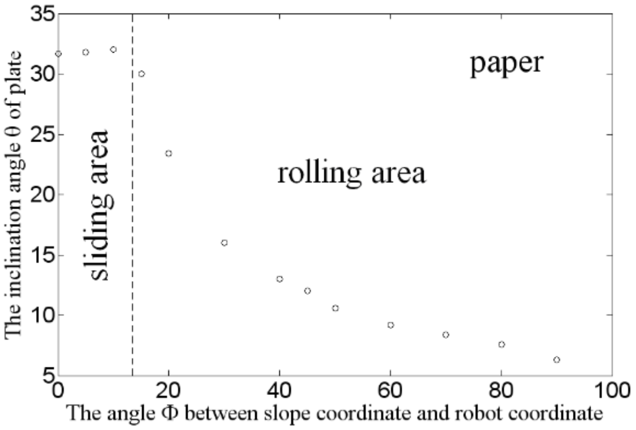

Figure 1. The relationship betweenθ and ϕ on the paper

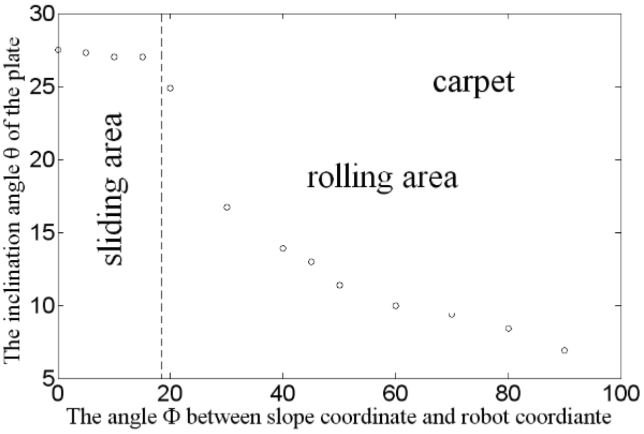

Figure 2. The relationship betweenθ and ϕ on the carpet

As ϕ increases, the robot makes sidewise movements on the slope, which means the robot makes downward movements along the rolling direction of the roller instead of moving along slope -*Y*. As shown in Fig. 9 and 10, the inclination angle of the slope decreases sharply. We define the sliding area of the robot in Fig 9 and 10 as the self-lock area, and the rolling area as the free rolling area. In the experiment, ϕ is 15°on paper and 18°on the carpet when the robot starts to make sidewise movements.

3. Self-lock characteristic of the mobile robot

There are several standard ways to solve this problem by using polytope theory. In this paper, we use the software Matlab to solve the problem. And we consider two different situations for the rectangle: the aspect ratio is 1:1 and the ratio is 3:2.

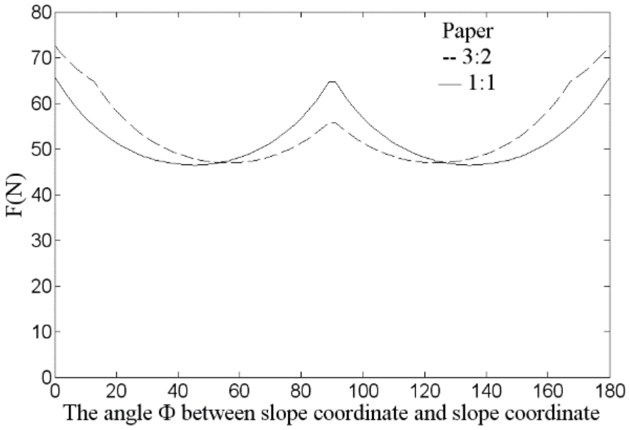

Figure 3. Relationship of F and ϕ on the paper

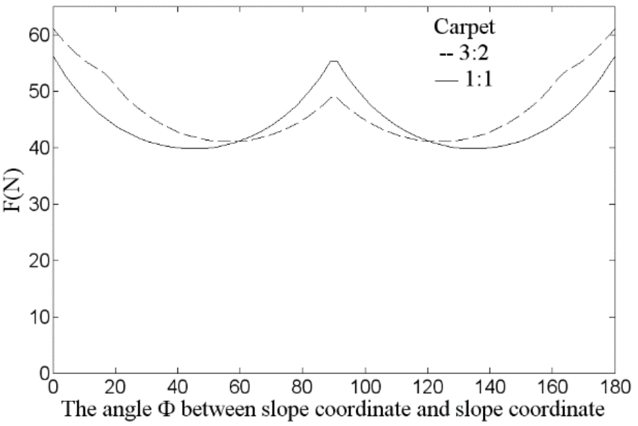

Figure 4. Relationship of F and ϕ on the carpet

As seen in Fig.3 and Fig.4, F denotes the pull force. And the difference in each direction of the respect ratio 3:2 is bigger than the respect ratio 1:1.

When the mobile robot is placed on the plane, there is no glide force. So in this situation, we use a force measurement tube made of a spring to pull the mobile robot. The parameters of the objective mobile robot are: the mass of the mobile robot M is 12Kg; *l* is 26.5 cm; the distance H between the center of the mobile robot and the center of the wheel is 9 cm; the radius of the wheel is 5 cm; φ is 45°. The results of the experiment are shown in Fig.5 and Fig.6.

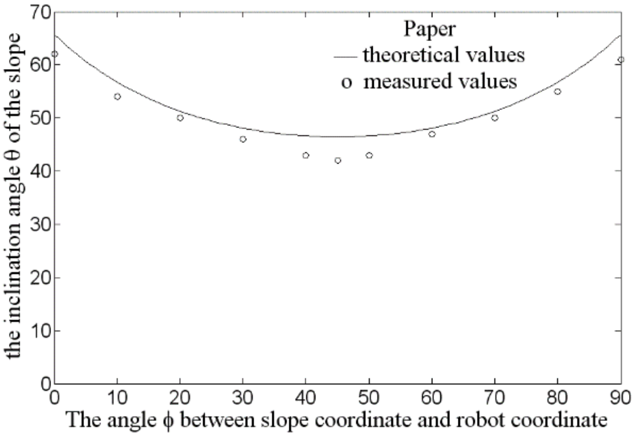

Figure 5. Experiment result on the paper

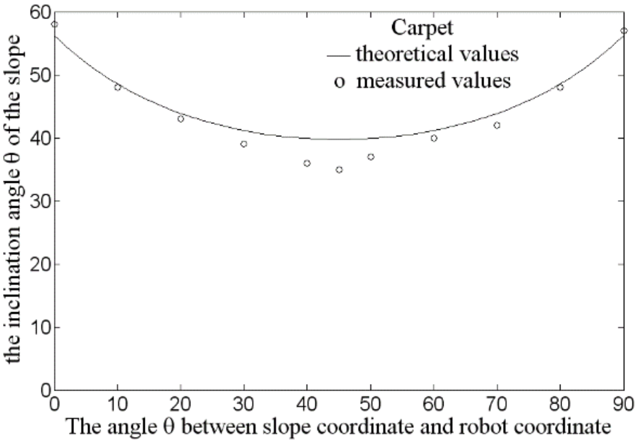

Figure 6. Experiment result on the carpet

The measured value accords with the theoretical value basically. Yet errors still exist due to machining and experiment deviation.

Since the mobile robot is on a slope, the gravity is not evenly distributed on four wheels. The connecting line between wheel 1 and wheel 3 intersects with the connecting line between wheel 2 and wheel 4. As the intersection point is at the center of the robot, we can conclude that wheel 1 and wheel 3 are subject to a 0.5Mg’s force of gravity, and it’s the same with wheel 2 and wheel 4.

Analysis on force conditions of wheel 1 and wheel 3 is shown in Fig.7.

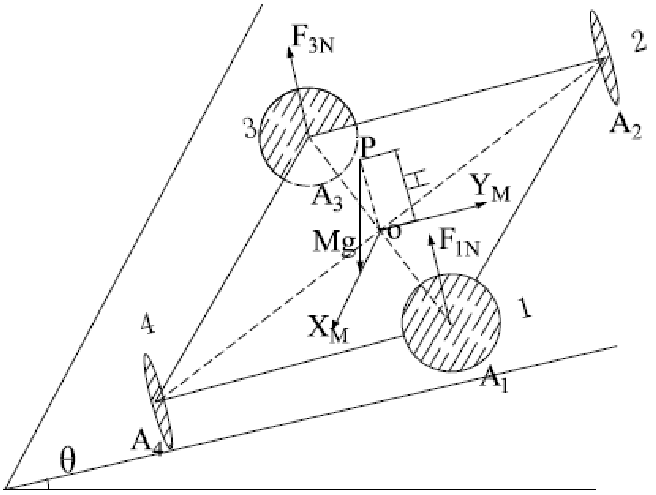

Figure 7. Force analysis of the wheel 1 and wheel 3

In Fig.7, P represents the center of the gravity of the robot. H represents the distance from point P to the plane formed by the centers of four wheels. A1, A2, A3 and A4 represent the contact points between each wheel and the slope.

Set A3 as the torque fulcrum, the torque equation for the plane perpendicular to the slope is:

$$2F_{1N}l + Mg\sin\theta\sin(\varphi+\phi)(\mathrm{H}+\mathrm{R}) = \frac{1}{2}Mgl\cos\theta \tag{1}$$

Eq. (15) becomes:

$$F_{1N} = \frac{Mgl\cos\theta - 2Mg\sin\theta\sin(\varphi+\phi)(\mathrm{H}+\mathrm{R})}{4l} \tag{2}$$

Set A1 as the torque fulcrum. The torque equation is:

$$2F_{3N}l - Mg\sin\theta\sin(\varphi+\phi)(\mathrm{H}+\mathrm{R}) = \frac{1}{2}Mgl\cos\theta \tag{3}$$

(17) Becomes:

$$F_{3N}=\frac{Mgl\cos\theta+2Mg\sin\theta\sin(\varphi+\phi)(\mathrm{H}+\mathrm{R})}{4l} \tag{4}$$

Similarly, we can achieve:

$$F_{2N}=\frac{Mgl\cos\theta-2Mg\sin\theta\sin(\varphi-\phi)(\mathrm{H}+\mathrm{R})}{4l} \tag{5}$$

$$F_{4N}=\frac{Mgl\cos\theta+2Mg\sin\theta\sin(\varphi-\phi)(\mathrm{H}+\mathrm{R})}{4l} \tag{6}$$

The range of $\mathrm{F_W}$ is:

$$-F_{iN}\mu_W \le F_{Wi} \le F_{iN}\mu_W, i=1\sim 4 \tag{7}$$

The range of $\mathrm{F_T}$ is:

$$-\mathrm{F_{iN}}\mu_T-\mathrm{f}_0 \le F_{Ti} \le F_{iN}\mu_T+\mathrm{f}_0, \mathrm{i}=1\sim 4 \tag{8}$$

Seen from formula (7) and (8), the ranges of $\mathrm{F_W}$ and $\mathrm{F_T}$ are related to the inclination angle of the slope, which means this problem can’t be solved by polytope theory. So in this paper, we solve the problem by using the trial-and-error method [16]. The values in theory and in experiment are shown in Fig.8 and Fig.9.

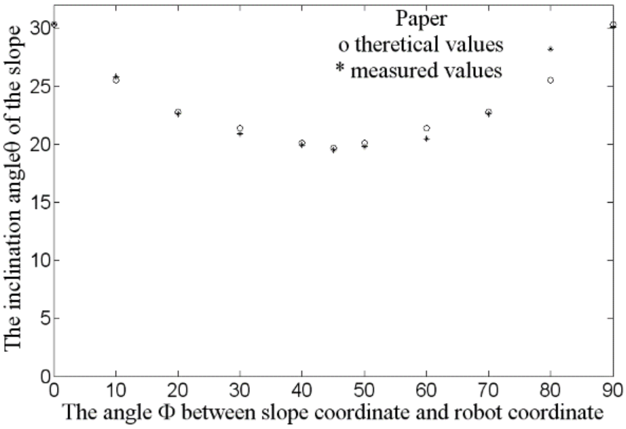

Figure 8. Experiment result on the paper

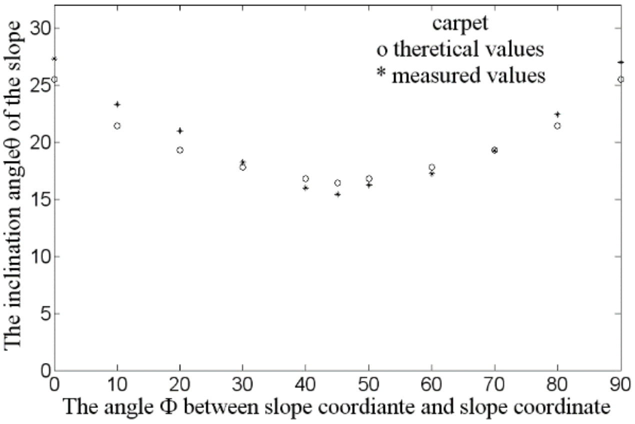

Figure 9. Experiment result on the carpet

As shown in Fig.8 and Fig.9, the error between theoretical values and measured values still exist although we test several times to reduce it.

4. Conclusion

This paper is focused on omni-directional mobile robots based on signal row alternate wheels, such as wheelchairs and forklifts. So our work offers the theoretical basis and data support for researches on stop performances of this kind of robot on the slope. In addition, our work lays the foundation for mastering the controllability and flexibility of such mobile robots.

Acknowledgements

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