Motion Planning Algorithm Based on Environmental Information for Mars Rover

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Abstract. In this paper, we propose a motion planning algorithm for Mars Rover to realize the smooth and steady action when crossing obstacles and ultimately achieve the purpose of autonomous movement. The research described in this paper includes the following aspects. Firstly, finish kinematics modelling and analyse some basic movement patterns when the rover is doing planar motion and get the results of the inverse kinematics. Then validate the result in the virtual simulation environment. Secondly, conduct the kinematics analysis for the Mars rover when it crosses some specific obstacles such as climbing a slope. Thirdly, get the optimized strategy of motion planning and determine the overall plan scheme when crossing obstacles.

Keywords: Kinematics modelling, inverse kinematics equations, crossing obstacles, motion planning strategies.

1 Introduction

In the past, the motion planning of the traditional robot mainly concentrated on path planning. This way actually regards the robot as a whole to study how it can effectively avoid obstacles in the environment. But on Mars, due to extremely complex pavements and environment, the Mars rover cannot be regarded as a black box. The structure of the robot, the over-obstacle capacity and many other aspects should be taken into account. The most important thing for the Mars rover is how to over the obstacles efficiently and ensure its safety, autonomy and high efficiency of its movement at the same time [1].

The research mainly studies that the Mars Rover analyses the environment information after obtaining the real-time environmental picture and decides how to control the motion of the 10 degrees of freedom based on the information [2].

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Fig. 1 The picture of the Mars rover in the laboratory

2 Planning Algorithm of Planar Motion for Mars Rover

The simplest situation is that the Mars rover moves on a plane without any obstacles. It has three basic kinds of movement patterns, namely: straight forward, backward, stop; spin around; rotation of large radius.

On the plane, any movement can be seen as a superposition of these three basic movement patterns. Viewing from the centre of mass of the Mars rover, the movement can be equivalent to two speeds: linear velocity V and angular velocity ω. Therefore, it is necessary to know the relationship between the rover's overall linear velocity V, the rotation angular velocity ω and its six wheel's speed. According to the structural characteristics of the rover, an inverse kinematics equations of motion on the plane is established [3].

The six wheels are denoted as No. 0 -5 in the anticlockwise direction, θ refers to the angle between the line connected by front wheels and the rover's centroid and the horizontal direction. β[i] means the pose angle of the No. i wheel.

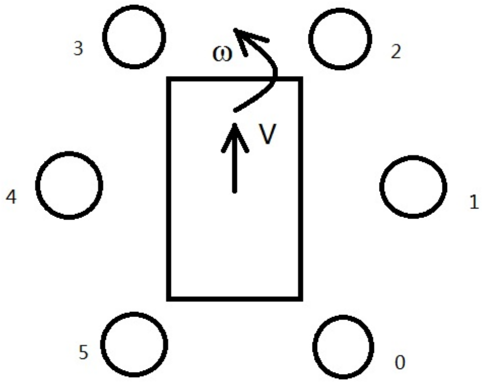

Fig. 2 The kinematics analysis of planar motion

$$\beta[0] = atan((\omega * L * sin(\theta))/(V - \omega * L * cos(\theta)) \quad (1)$$

$$\beta[2] = -atan((\omega * L * sin(\theta))/(V - \omega * L * cos(\theta)) \quad (2)$$

$$\beta[3] = -atan((\omega * L * sin(\theta))/(V + \omega * L * co\,s(\theta)) \quad (3)$$

$$\beta[5] = atan((\omega * L * sin(\theta))/(V + \omega * L * cos(\theta)) \quad (4)$$

$$V[0] = -(V - \omega * L * cos(\theta))/cos(\beta[0]) \quad (5)$$

$$V[1] = -(V - \omega * L) \quad (6)$$

$$V[2] = -(V - \omega * L * cos(\theta))/cos(\beta[2]) \quad (7)$$

$$V[3] = (V + \omega * L * cos(\theta))/cos(\beta[3]) \quad (8)$$

$$V[4] = (V + \omega * L) \quad (9)$$

$$V[5] = (V + \omega * L * cos(\theta))/cos\,\beta([5]) \quad (10)$$

3 Planning Algorithm of Crossing Over Obstacles and Simulation Verification

Three factors needs to be considered when the Mars rover goes through obstacles in a real-time environment: security, stability, economy. The rover can efficiently go through obstacles if its motion planning method meets these three conditions. Security is to determine the strongest ability of going through obstacles and this can provide a theoretical basis for the rover's traversability. Stability is that the rover can keep its direction of motion unchanged after going through obstacles. That means it can self-correct its direction when it deviates from its original direction. Economy means that most of the current planning methods set the same motion parameters for each wheel, this planning method will result in the parasitic power loss. The reason is the incoordination between different drive units, it may results in the wheel's slip. So kinematic analysis need be done when the rover goes through obstacles. By this way, a more efficient pattern for crossing obstacles can be achieved [4].

3.1 Motion Planning of Uphill

The whole idea for the motion plan of climbing is to keep the motor's rotation speed of the wheels which are on the ground constant, then the speed of the wheel which is on the slope changes in real time. According to the geometric relationship, the relationship between the speed of the wheels on the slope and the speed of the wheels on the ground can be solved in the ideal situation. Controlling the speed of the uphill wheels based on this solution will reduce the possibility of the occurrence that other wheels slip so that the power consumption of the motor achieves a minimum value.

This method firstly analyses one situation of uphill: Only the front wheel climbs on the slope while the middle and the back wheel moves on the ground. It sets the original moments which means t = 0 corresponds to the moment that the front wheel begins to climb on the slope.

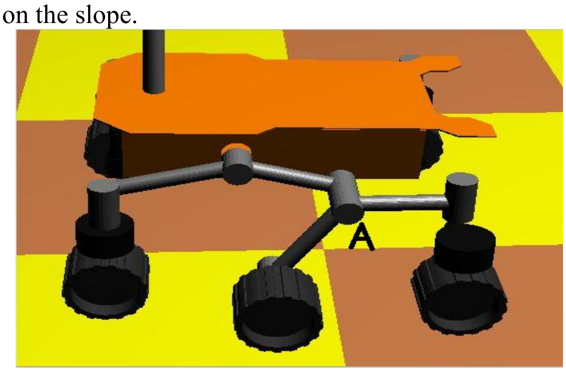

Fig. 3 Mars rover in Webots simulation environment

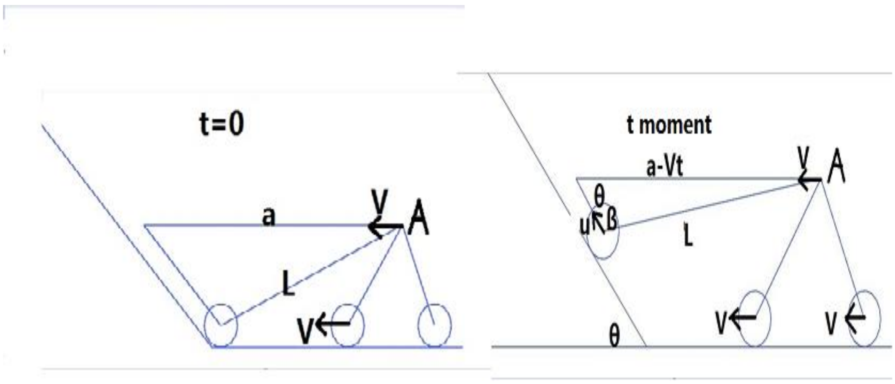

Fig. 4 The kinematics analysis of the uphill of the Mars rover

In the analysis, the overall forward speed of the rover is denoted as V, the speed of the uphill wheel u, the slope angle θ.

By the triangle law of cosines:

$$\frac{L}{sin\theta} = \frac{a-Vt}{sin\beta} \tag{11}$$

By the rule that the speed along the direction of the rod should be the same:

$$Vcos(180 - \theta - \beta) = ucos(180 - \beta) \tag{12}$$

$$L = 0.68 \tag{13}$$

$$a = 0.62 + \frac{0.28}{tan\,\theta} \tag{14}$$

$$u = \frac{cos(\theta+\beta)}{cos\beta}V = \frac{cos(\theta+pi-asin(\frac{a-Vt}{L}sin\theta))}{cos(pi-asin(\frac{a-Vt}{L}sin\theta))}V \tag{15}$$

If the climbing wheel is denoted as No1, the other wheels are denoted as 2-6, the motion planning equation is:

$$V_1 = \frac{cos(\theta+pi-asin(\frac{a-Vt}{L}sin\theta))}{cos(pi-asin(\frac{a-Vt}{L}sin\theta))}V \tag{16}$$

$$V_2 = V_3 = V_4 = V_5 = V_6 = V \tag{17}$$

Note that the speed of the climbing wheel changes with time while the other wheels' speed is consistent with the overall rover forward speed. The rover uses DC servo motor which can achieve real-time change in velocity.

According to the results of the above plan, the speed curve of the front wheel when climbing 30° and 20° slope is as follows:

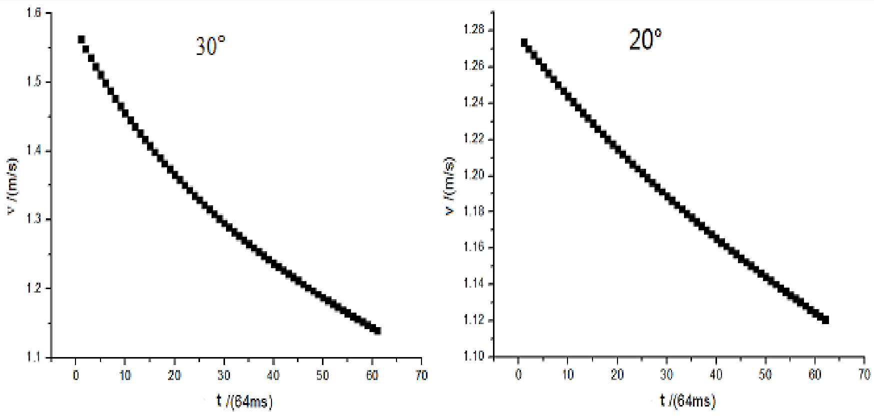

Fig. 5 The speed curve of the front wheel when climbing 30° and 20° slope

The unit of time is taken as 64ms because the cycle that the Webots program updates all of the values is 64ms.

3.2 Webots Simulation Verification

In Webots, this method makes the simulation of the above planning strategy. Since the slip of the wheel may happen in real environments, it will be difficult to see the difference between different strategies. In Webots simulation, this method sets the coefficient of friction between the wheels and the ground or the slope to a very big value to ensure the wheels' pure rolling. In this situation, the results of simulation will be more obvious.

Fig. 6 The simulation of the process of uphill using two different planning strategies

When the rover climbs with its six wheels at the same speed, it can be seen that the middle wheel hangs in the air. This phenomenon is not difficult to understand. Since the front wheel is uphill, the rear wheel moves forward on the ground, if these two wheels keep the same speed, then the body will inevitably be compressed resulting in the middle wheel idle off the ground. At the same time, the rear wheel on the ground bears much larger load. Besides, the motor is damaged due to the unreasonable velocity distribution.

When the process of climbing is controlled by the results calculated above, that means the speed of the climbing wheels change in real-time, the middle wheel is always close to the ground and the entire body can smoothly climb on the slope. The data shown in the console area in the bottom of the right figure is the real time speed of the uphill wheel. This planning strategy which conforms to the kinematic and geometry relationship can achieve the optimization of energy and protect of the motor, so that the rover can theoretically cross obstacles efficiently.

The other kinds of climbing such as downhill are analysed and verified using the similar approaches, the process of derivation is omitted here.

4 Overall Planning Algorithm for Crossing Over Obstacles

To combine the motion planning algorithm with the vision algorithm, the planning strategy need be changed according to the real-time working conditions of the rover [5].

The visual part of the algorithm analyses nine kinds of simple working conditions of the rover including uphill, climbing across the vertical ladder or simply not able to pass the obstacle. The motion planning part will take the corresponding planning strategy to control the motion of the rover based on the working condition it gets from the vision part [6].

For example, when the working condition is determined to be No 7 which corresponds to straight uphill of the rover, the visual algorithm will return some parameters to the motion planning algorithm such as the distance from the rover to the slope, the slope angle and the height of the slope.

The following figure is a world model established in Webots virtual simulation environment to verify the effectiveness of the motion control strategy.

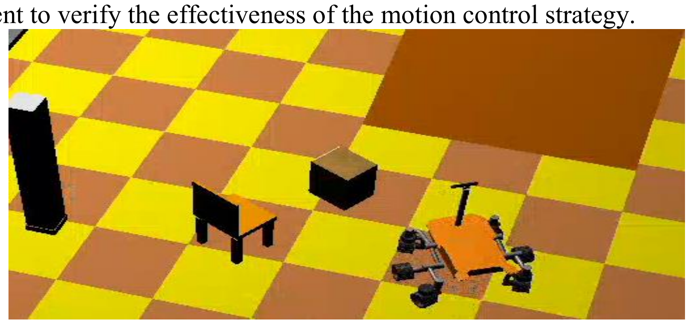

Fig. 7 World model established in Webots virtual simulation environment

This method actually combines all kinds of obstacles to make a target database. Based on this idea, the overall planning algotithm can be summarized as follows:

Firstly Kinect vision sensor mounted on the rover gets an image of real-time environmental information, the image mosaic algorithm can obtain a 4 x 4 matrix after coping with this image and then get the rover's pose information. At the same time, the vision algorithm recognizes the obstacle and compare it with the standard obstacle in the target database established previously. Then some of the characteristic parameters can be obtained and the current working condition of the rover is determined [7].

If the obstacle is beyond the rover's crossing ability, a fuzzy path planning need be done, the main task is to bypass the obstacle and the specific method is to plan the path of the rover. However, this is not the focus of this method. If the obstacle is within the rover's crossing ability, the motion planning involving 10 degrees of freedom need be done to achieve the efficiency of going through obstacles. According to the type of the obstacles and characteristic parameters, strategy for going through obstacles can be determined. This method focuses on the rotation velocity and pose planning of each wheel based on the strategy discussed previously.

5 Conclusion

In this paper, we propose a motion planning algorithm for Mars Rover and validate its effectiveness in the virtual simulation environment. We achieve the purpose of autonomous movement by determine the overall plan scheme when crossing obstacles.

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