Modeling and Simulation of Mobile Robot Based on VREP

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Keywords: VREP, Mobile Robot, Modeling, Simulation, Kinematics, Dynamics.

Abstract: In view of the problems of high computational complexity and poor repeatability in traditional mobile robot modeling and simulation methods, this paper studied the rapid modeling and simulation of mobile robot based on VREP to improve computational efficiency and repeatability. Firstly, the motion analysis and modeling of mobile robot are introduced, and the advantages of its application in mobile robot simulation are analyzed. Then, the modeling method of mobile robot based on VREP is described in detail, including the selection of robot model, the setting of kinematics and dynamics parameters. Finally, the feasibility and effectiveness of the proposed modeling method are verified through simulation experiments using VREP software.

1 INTRODUCTION

Mobile robot is a kind of robot system with wide application prospect, which can move and perform tasks autonomously in complex environment. However, due to the complexity of its mechanical structure and control system, traditional experimental methods are difficult to meet the needs of systematic research and testing of mobile robots. Therefore, using simulation technology to model and simulate mobile robots is an effective research method. Traditional mobile robot modeling and simulation methods suffer from high computational complexity and poor repeatability. In addition, most of the existing mobile robot modeling and simulation tools require programming knowledge, which is difficult for non-programmers to operate. The mobile robot based on VREP is a mechanical device that can autonomously perform certain tasks. Their invention is aimed at helping or replacing humans to perform a series of repetitive and laborious tasks, such as production and manufacturing, civil construction, or hazardous work (Rohmer, 2013).

The significance of this research lies in the fact that through the motion analysis and modeling of mobile robots, and the development of a mobile robot modeling and simulation system based on VREP, the research and development efficiency and quality of mobile robots can be improved, and the development and application of mobile robot technology can be promoted.

2 MOBIL ROBOT MOTION MODEL BUILDING

This section elaborates on the modeling method of mobile robots based on VREP, including the selection of robot models, setting of kinematic and dynamic parameters, addition of sensors and controllers, and other related details. The design of the robot model is also explained in detail to ensure the accuracy and credibility of the simulation results.

2.1 Mobile Robot Modeling Methodology

In the process of robot modeling, it is essential to have a certain methodology, which can provide clearer ideas and guidance. There are three commonly used robot modeling methodologies:

1)Analytical Modeling Methodology
Analytical modeling is a modeling method widely used in the field of robotics. It is based on physics and mathematical theory and uses formulas and equations to describe the robot. This method has a clear idea and is suitable for modeling complex robot systems. It can highly simulate robot behavior and carry out corresponding control and optimization applications. But correspondingly, the mathematical and physical knowledge required for analytical modeling is in-depth and comprehensive, and the quality requirements for modelers are also higher.

Zhang, Z., Liu, J., Wang, G., Zhang, C., Liu, Y. and Yang, L.
Modeling and Simulation of Mobile Robot Based on VREP.
DOI: 10.5220/0012274200003807

In *Proceedings of the 2nd International Seminar on Artificial Intelligence, Networking and Information Technology (ANIT 2023)*, pages 75-79
ISBN: 978-989-758-677-4

2)Experimental Modeling Methodology

Experimental modeling is a method based on experimental data and simulation verification. It usually involves many aspects such as robot movement and perception ability, and data sources are also unique, such as sensors, simulators, and field environments. The experimental modeling has good adaptability and practicability, and can effectively reflect the actual behavior and working environment of the robot. However, if the data source is not reliable, the modeling accuracy will be affected accordingly.

3) Deep Learning Modeling Methodology

Deep learning modeling is a new technology in the field of robotics in recent years. It uses the idea of artificial neural networks to extract key features from large amounts of data for modeling. Deep learning modeling has good intelligence and adaptive ability, which can make rapid response and decision according to different situations. However, the large sample set and powerful computing power required for deep learning modeling are also issues that cannot be ignored.

To sum up, establishing a suitable robot modeling methodology is an important means to ensure the effectiveness of robot simulation and control. Only by selecting the corresponding methodology for modeling, can we better simulate the actual behavior of the robot and carry out the corresponding optimization and application. In this paper, the first and the second are combined to promote the experiment by theory, and the experiment then improves the theory, which complements each other, and provides the foundation for the tasks of autonomous navigation, path planning, obstacle avoidance and so on.

2.2 Mobile Robot Motion Model Analysis

To improve the generality of mobile robot modeling, ordinary tires with sliding steering are used in this modeling. As shown in Figure 1, taking wheel A as an example: it can be decomposed into V_{1x} and V_{1y} (that is, lateral velocity and longitudinal velocity), where the lateral velocity is generated by the sliding friction between the tire and the ground, and the longitudinal velocity is generated by the rolling friction between the tire and the ground. Therefore, the turning motion is generated by sliding friction. It can be inferred that the rolling friction is actively generated by the motor output torque driving the wheel rotation, while the sliding friction is passively generated due to the inconsistent speeds of the four wheels.

In order to simplify the model, the analysis is put forward in the ideal state, that is: (1) no idling phenomenon occurs when the robot wheel rolls; (2) The mass of the robot body is evenly distributed and located on the geometric longitudinal symmetry line of the robot, but not necessarily on the geometric transverse symmetry line. As can be seen from Figure 1, the combined velocity direction of the ideal contact point between the tire and the ground (that is, the center of the wheels A, B, C, D) is perpendicular to the radial direction of the rotation radius, and can be decomposed into the longitudinal component speed along the wheel rolling direction and the transverse component speed along the motor axis.

As can be seen from Figure 1, the two front wheels are subjected to lateral forces to the left, while the two rear wheels are subjected to lateral forces to the right. The two sets of lateral forces are opposite in direction, which just makes the robot rotate around the center of mass. When forward motion is superimposed, the robot appears to move in a circular motion.

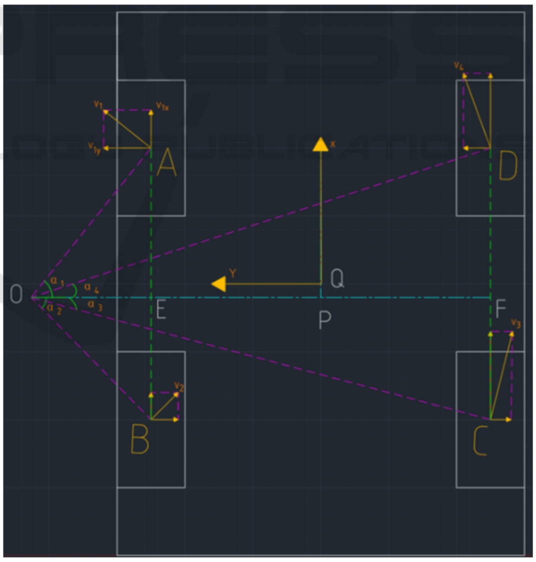

Figure 1: Motion model analysis of four-wheel drive mobile robot.

From the longitudinal velocity analysis of the left wheel, we can see:

$$\begin{cases} v_{1x} = v_1 \cdot \cos\alpha_1 \\ v_{2_x} = v_2 \cdot \cos\alpha_2 \end{cases} \tag{1}$$

Formula , v_{1x} and v_{2x} are respectively the linear velocities of wheel A and wheel B;

α_1 and α_2 are ∠ AOP and ∠ BOP respectively, and P is the geometric center of mass.

From formula 1, $v_{1x} = v_{2x}$ that is, the longitudinal component velocity of wheel A and wheel B is the same, that is, the component velocity in the X direction is the same. By the same token, the longitudinal velocities of wheels C and D are the same.

From the transverse velocity analysis of the front wheel, it can be seen that:

$$\begin{cases} v_{1y} = v_1 \cdot \sin\alpha_1 \\ v_{4y} = v_4 \cdot \sin\alpha_4 \end{cases} \tag{2}$$

Formula , v_{1y} and v_{4y} are respectively the linear velocities of wheel A and wheel D;

α_1 and $\alpha 4$ are ∠AOP and ∠DOF respectively.

According to equation 2, $v_{1y} = v_{4y}$, that is, the longitudinal component velocity of wheel A and wheel D is the same, that is, the component velocity in the Y direction is the same. By the same logic, the longitudinal velocities of wheels B and C are the same.

To sum up:

$$\begin{cases} v_{1x} = v_{2x} = v_L \\ v_{3x} = v_{4x} = v_R \\ v_{1y} = v_{4y} = v_F \\ v_{1y} = v_{4y} = v_B \end{cases} \tag{3}$$

Formula , v_L and v_R represents the longitudinal component speed of the left and right wheels respectively, v_F and v_B represents the transverse component speed of the front and rear wheels respectively.

2.3 Mobile Robot Motion Model Building

The motion model of a four-wheel drive mobile robot is quite complex, so for ease of calculation, the four-wheel motion is simplified and treated as an equivalent two-wheel differential drive motion model. As shown in Figure 2, a virtual two-wheel simulation of four-wheel motion was established, with OP as the horizontal axis and PQ as the vertical axis. It was assumed that the virtual left and right wheels were located outside the point vehicle and close to the vehicle body respectively. The length of virtual wheel spacing D2 was not necessarily equal to that of real wheel spacing D1, and virtual wheel spacing D2 was dynamically changing.

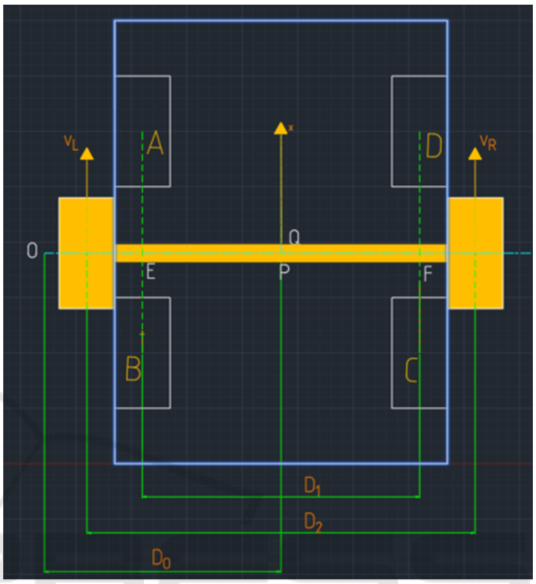

Figure 2: Motion model establishment of four-wheel drive mobile robot.

From this analysis: if there is no rotational motion (no slip), only v_L and v_R, both v_F and v_B are 0, then D1=D2; However, if there is rotational motion, i.e. the velocities are not zero and there is a slip phenomenon, the actual situation changes. This means that the angular velocity calculated based on the v_L and v_R and D1 is not the true angular velocity. The degree of slip varies with different rotational motions, which affects the actual angular velocity differently, so the virtual wheel base D2 is dynamically changing.

The simplified motion model can be expressed as:

Forward kinematics model:

$$\begin{bmatrix} v_O \\ \omega_O \end{bmatrix} = \begin{bmatrix} \frac{v_L + v_R}{2} \\ \frac{v_L - v_R}{D_2} \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ \frac{1}{D_2} & -\frac{1}{D_2} \end{bmatrix} \begin{bmatrix} v_L \\ v_R \end{bmatrix} \tag{4}$$

Inverse kinematics model:

$$\begin{bmatrix} v_R \\ \omega_L \end{bmatrix} = \begin{bmatrix} v_P + \frac{D_2\omega_P}{2} \\ v_P - \frac{D_2\omega_P}{2} \end{bmatrix} = \begin{bmatrix} 1 & \frac{D_2}{2} \\ 1 & -\frac{D_2}{2} \end{bmatrix} \begin{bmatrix} v_P \\ v_P \end{bmatrix} \tag{5}$$

3 VREP SIMULATION EXPERIMENT DESIGN AND RESULT ANAYLYSIS

A simulation experiment was conducted using VREP software on the established mobile robot model. The overall design scheme mainly includes software design and experimental design. The software design includes four aspects: modeling, path planning, adding sensors, and programming using Lua language. The specific steps are as follows:

① Establish the body of the mobile robot. Add a rectangular body with a length of 30cm, a width of 20cm and a height of 10cm into ADD, then add four cylinders to the body as wheels, and add four rotating joints to the four wheels, so that the cylinder can drive the body to move.

② Build a simulation environment and plan the path of the mobile robot. Click Add path, select the circular path in the category, and then click Track Edit to edit the 16 track points. The trajectory should be as smooth as possible to ensure that the robot does not encounter positional deadlocks during the simulation.

③ Add sensors. Select Perspective sensor in the sensor type to change the sensor position coordinates. The same method adds two more sensors and renames them left, center, and right. Make sure the trajectory is within the detection range of the sensors.

④ Write the motion program. Use the forward and inverse kinematics equations of the robot in Chapter 2 to model the programming. The experimental design includes the correct connection between each part of the experiment, reasonable path curves, correct programming, and good programming habits to achieve the final simulation result. Figure 3 shows the simulation of the mobile robot tracking the path.

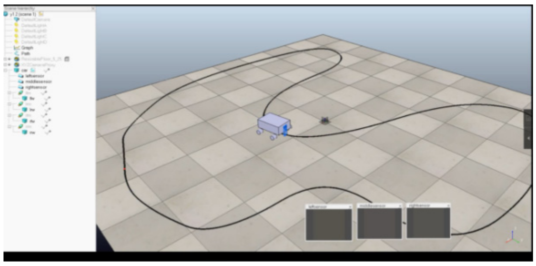

Figure 3: Tracking simulation diagram of mobile robot.

In VREP, robot control programs can be written using LUA scripts to achieve robot path tracking. By using the grayscale sensors and the odometer multi-sensor fusion algorithm, different sensor information can be fused to obtain more accurate and comprehensive robot environment perception information, thus improving the robot's autonomous navigation and obstacle avoidance capabilities.

As shown in Figure 3, the three pictures in the lower right corner are the information collected by the three grayscale sensors, that is, the information of the three sensors on the left, middle and right. When the robot deviates to the left, it can refer to the information from the left sensor to move forward and make corrections.Similarly, the right side is the same as the left side; When the robot moves forward with the middle sensor as the reference, it can maintain a straight trajectory and reach the target point. Through simulation experiments, this method can accurately simulate the motion and sensor data of mobile robots. Specific experimental design includes robot path planning, motion control and sensor data acquisition, etc. Ultimately,the robot can navigate the experimental destination with high precision and the controller has stable performance. The experimental results show that the mobile robot model can improve the accuracy of multi-sensor fusion data and ensure the motion accuracy of the simulated robot. Through the above experimental simulation, the feasibility and effectiveness of the proposed modeling method are verified.

4 CONCLUSION

This article studies the modeling and simulation technology of mobile robots based on VREP. Through the analysis of mobile robot modeling methods and mobile robot motion analysis, a mobile robot motion model is established. At the same time, VREP software is used to simulate its modeling, and multi-sensor fusion is added to achieve target point tracking function and improve accuracy. The research on multi-sensor fusion of mobile robots based on VREP is an important research direction in the field of robotics, which can improve the perception and autonomous control capabilities of robots and contribute to the development of robotics technology. For example, in rescue missions, multiple sensors can be fused to achieve precise positioning and rescue operations for trapped individuals, improving rescue efficiency and success rate. VREP software can further explore the use of other simulation software and the improvement of robot modeling methods to meet more complex application requirements. The research on multi-sensor fusion of mobile robots can be applied to fields such as robot autonomous navigation, environmental monitoring, and rescue missions.

ACKNOWLEDGMENTS

This work is greatly appreciated for the strong support from the Engineering Research Center of Robot and Intelligent Manufacturing, Universities of Shaanxi Province.

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