Slave Coordinated Speed Analysis and Coordinated Control Method

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Abstract. When the container is being repaired, it is necessary to transfer the container to be repaired between the temporary storage area and the repair area. Due to the large size, when manually transported by forklift, the line of sight is blocked, there is a great safety hazard and efficiency. It is relatively low, and it is inconvenient to use a single mobile robot to carry it. Therefore, to solve this problem, a dual-mobile robot collaborative operation system is developed, and two mobile robots are used to move containers together to complete container maintenance and handling. Through the analysis of the cooperative handling of the dual mobile robots, a mathematical model of the cooperative movement of the dual mobile robots is established, and kinematics analysis is carried out to provide a theoretical basis for controlling the cooperative operation of the dual mobile robots.

1. Introduction

In recent years, the research of mobile robots has become more and more abundant, and one of the most discussed aspects of mobile robotics is multi-mobile robots [1]. Later, group mobile robots appeared slowly, which have stronger superior performance than single mobile robots, such as parallelism, flexibility, robustness. [2]. While the application scale of industrial mobile robots continues to expand, the technical requirements for mobile robots are constantly increasing. The requirements of complex processing technology in industrial production make the traditional single-mobile robot working mode difficult to handle [3]. For example, when a mobile robot is welding a workpiece, the workpiece is often required to be able to change its posture so that the mobile robot can weld the workpiece at a more reasonable position and angle; when carrying a workpiece with a larger volume and weight [4], It often requires multiple mobile robots to work together to be competent. Therefore, the mobile robot system is currently being upgraded from a single mobile robot task mode to a multi-mobile robot collaborative work mode [5]. As a common key technology of mobile robots, collaborative operation of mobile robots has also been written into my country's mobile robot industry development plan by the Ministry of Industry and Information Technology.

2. Kinematics model of dual mobile robot

According to the cooperative form of the dual mobile robots studied in this paper, the two mobile robots are located at the opposite corners of the container center[6]. In order to facilitate the establishment of the cooperative motion equation of the dual robots, the following assumptions are made:

(1) The entire dual-mobile robot collaborative system is a rigid body, and the wheels are rigid wheels;
(2) The wheels of the mobile robot are not sliding with the ground;
(3) The mobile robot moves on the plane;
(4) Ignore the influence of the load on the body motion.
The coordinated motion of dual mobile robots is mainly divided into linear motion and circular arc motion. In linear motion, the coordinated operation can be realized as long as the master mobile robot and the slave mobile robot have the same speed [7]. The following focuses on the analysis of arc motion. There are three situations in arc motion: the main mobile robot enters the arc, and the slave mobile robot does not enter the arc; the master, all the slave mobile robots enter the arc; the main mobile robot exits the arc, and the slave mobile robot is still in the arc, and it is assumed that the speed of the master mobile robot remains constant throughout the movement, as shown in Figure 1.

![Figure 1. Arc kinematics model of dual mobile robot](image1)

2.1. The main mobile robot enters the arc, but the slave mobile robot does not enter the arc
Assuming that the main mobile robot's speed $v_1$ is always constant, as shown in Figure 2, the kinematics analysis is performed, and the distance traveled by the mobile robot is $L_2$, then:

$$L_2 = L + \int_0^t v_x \, dt - x$$  \hspace{1cm} (1)

$$x = \sqrt{L^2 - y^2}$$  \hspace{1cm} (2)

$$y = \int_0^t v_y \, dt$$  \hspace{1cm} (3)

$$v_y = v_1 \sin \alpha$$  \hspace{1cm} (4)

$$v_x = v_1 \cos \alpha$$  \hspace{1cm} (5)

$$\alpha = \frac{\dot{\theta}}{r}$$  \hspace{1cm} (6)

$$v_2 = \frac{dx}{dt} = v_x \cdot \frac{dx}{dt}$$  \hspace{1cm} (7)

$$\frac{dx}{dt} = \frac{\dot{y}}{L^2 - y^2}$$  \hspace{1cm} (8)

$$y = r - r \cos \alpha$$  \hspace{1cm} (9)

$$v_2 = v_1 \cos \frac{\dot{\theta}}{r} \cdot \left[ (r - r \cos \frac{\dot{\theta}}{r}) \cdot \frac{v_1 t}{r} \right] \cdot \frac{v_1 \sin \frac{\dot{\theta}}{r}}{L^2 - (r - r \cos \frac{\dot{\theta}}{r})^2}$$  \hspace{1cm} (10)

![Figure 2. The main mobile robot enters the arc](image2)
2.2. Master and slave mobile robots all enter the arc
As shown in Figure 3, when the two mobile robots all enter the arc, the speed of the two mobile robots should be the same $v_1 = v_2$, that is, make a uniform circular motion along the arc.

![Figure 3. The master and slave mobile robots all enter the arc](image)

2.3. The main mobile robot drives out of the arc, while the slave mobile robot is still in the arc
As shown in Figure 4, assuming that the speed $v_1$ of the main mobile robot is constant when going out, the displacement during time $t$ is $S$, which can be obtained from the geometric relationship as shown in the figure.

$$L\cos\beta - r\cos\alpha = s = v_1 t \quad (11)$$
$$r\sin\alpha + L\sin\beta = r \quad (12)$$

For (11) and (12), respectively, the derivative of time $t$ is obtained,

$$L(-\sin\beta)\omega_2 - r(-\sin\alpha)\omega_1 = v_1 \quad (13)$$
$$r(\cos\alpha)\omega_1 + L(\cos\beta)\omega_2 = 0 \quad (14)$$

Can be obtained from (14),

$$\omega_2 = -\frac{r\cos\alpha}{L\cos\beta} \cdot \omega_1 \quad (15)$$

Can be obtained from (12),

$$\beta = \arcsin\left(\frac{r-r\sin\alpha}{L}\right) \quad (16)$$

Substitute (15) and (16) into (13) to get,

$$v_1 = \frac{r\omega_1 \sin(\alpha + \beta)}{\cos\beta} \quad (17)$$
$$\sin\beta = \frac{r - r\sin\alpha}{L} \quad (18)$$

When $\frac{r}{L} = \lambda$, Available,

$$\sin\beta = \lambda - \lambda\sin\alpha \quad (19)$$

Using Newton's binomial theorem to expand the series, we get,

$$\cos\beta = 1 - \frac{1}{2}(\lambda - \lambda\sin\alpha)^2 - \frac{1}{8}(\lambda - \lambda\sin\alpha)^4 - \cdots \quad (20)$$

This series converges very quickly. When $\lambda \leq 1/3$, you can accurately get the three digits after the decimal point by taking the first two terms. Therefore,

$$\cos\beta \approx 1 - \frac{1}{2}(\lambda - \lambda\sin\alpha)^2 = \frac{1}{2} - \frac{\lambda^2}{2} + \lambda^2\sin\alpha + \cos2\alpha \quad (22)$$

Substitute (22) into (11),

$$S = r\left(\frac{1}{2\lambda} - \frac{\lambda}{2} + \lambda\sin\alpha + \frac{\cos2\alpha}{\lambda} + \sin\alpha\right) \quad (23)$$

Deriving (23) with respect to time,
When \( L \geq r \), the central angle \( \alpha \) from the mobile robot can be expressed as,

\[
\alpha = \omega t
\]  

(25)

Simplify finally,

\[
v_1 = v_2 \left( \lambda + 1 \right) \cos \alpha \left( \frac{v_2}{r} t \right) \frac{2\sin(2\alpha)}{\lambda} \sin\left(2\left(\frac{v_2}{r} t\right)\right)
\]  

(26)

3. Experiment preparation analysis

Through the detailed analysis of the arc motion in three stages above, the arc kinematics equation of the dual mobile robot is obtained, which describes the motion process of the dual mobile robot cooperative operation, and draws the speed circle as shown in Figure 5 according to the kinematic equation Arc, which provides a theoretical basis for the realization of cooperative motion control of dual mobile robots.

In the dual mobile robot experiment, the trigger switches are set at point A and point B respectively. First, in the time period from \( t_0 \) to \( t_1 \), when the master mobile robot reaches point A, a speed command (10) is issued to the slave mobile robot, so that the dual mobile robot The coordinated completion enters the arc phase; secondly, during the time period from \( t_1 \) to \( t_2 \), when the mobile robot reaches point A, a speed command \( v_1 = v_2 \) is issued to the slave mobile robot, so that the dual mobile robots cooperate to complete a uniform circular arc motion; finally In the time period from \( t_2 \) to \( t_3 \), when the master mobile robot reaches point B, it will issue a speed command (26) to the slave mobile robot, so that the dual mobile robots coordinate to complete the arc motion.

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Figure 5. The main mobile robot moves out of the arc

4. Conclusion

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