Design and Development of an Omni-Directional Mobile Robot for Logistics of Printing Enterprise

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***Abstract* — Based on printing enterprise layout, an omni-directional mobile robot with zero torque is designed by the three Swedish wheels structure. First of all, we describe the mechanical design and the motion model of the robot in detail. A navigation logic system is proposed combining positioning of incremental photoelectric encoder and a path planning algorithm based on the Dijkstra algorithm. Then, taking the workshop logistics channel as an example, the path planning simulation is implemented on the MATLAB platform. The omni-directional autonomous motion of the robot is realized. It is an effective attempt to improve the intelligence of the logistics system.**

Keywords - omni-directional mobile robot; motion model; localization; path planning; navigation

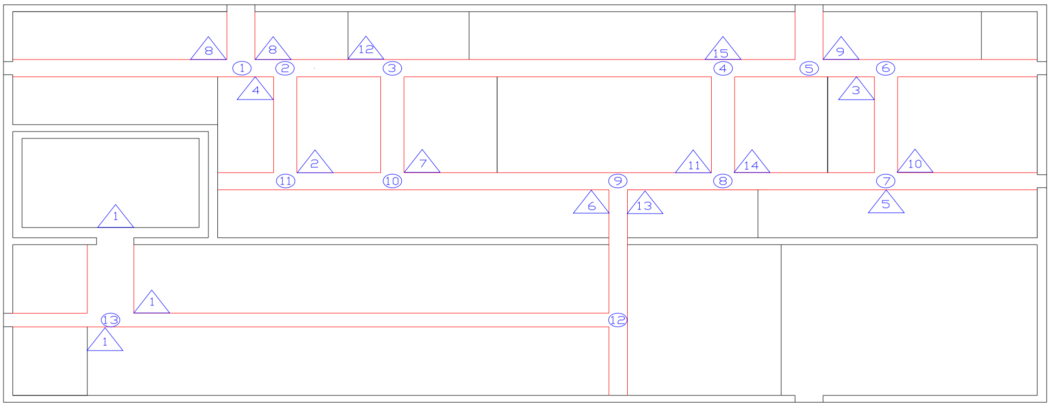
I. INTRODUCTION

Since the discrete manufacturing enterprises are mostly in the transition from traditional production mode in modern production mode, Automated Guided Vehicle (AGV), in logistic, has the limitation of movement flexibility and intelligence. On the contrary, the omni-directional mobile robot can move along any trajectory under the premise of the body posture unchanged, and realize the omni-directional mobility. It is the creative direction of the mobile robot, and has been the subject of research[1]. Among, for configuration innovation of driving wheel, the Swiss federal institute of technology university developed robot tremolo, with three spherical wheels arranged along the circumference of the triangle, each controlled by a motor and hung up by contact points[2]. Carnegie Mellon university developed an omni-directional mobile robot with three Swedish wheels installed under the structure of radial symmetry and the robot Uranus using four Swedish wheels[2]. About robot localization, Ibraheem M used EKF to fuse the encoder and gyroscope, and improved the stability of the system[3]. Cho B et al. used the Calman filter (KF) to fuse the encoder, the electronic compass and the gyroscope in order to reduce the accumulated error of the dead reckoning effectively[4]. In the aspect of navigation, under the assumption that robot driver is big enough, Purwin got a time optimal trajectory planning algorithm with less computation[5]. Alireza used busier curve to accomplish real-time trajectory planning algorithm[6]. Li Yuanchen proposed an improved algorithm based on Dijkstra algorithm for the shortest path search, which can improve the search efficiency by setting up a high efficiency priority search area[7]. On the basis of the Dijkstra algorithm, Yin Chao used a binary tree structure to enhance the efficiency of the algorithm[8]. This study designed a circular omni-directional mobile robot and discussed the related technologies in detail. Results played a significant role to improve enterprise logistics in automatic and intelligent degree.

II. WORKSHOP LAYOUT

X printing enterprise was established in August 2001, is an enterprise uniting design, plate making, and binding. By determining the size of the site facilities layout, we got the area of the present situation of workshop layout: the printing workshop area is 6050m^2, of which the length is 110mand the width is 55m, the channel width is about 2-3m. The printing workshop, the binding workshop, and the division of inner region are simplified mapped according to the proportion of1:100, as showed in figure 1. The following symbols are used in the modeling:

- Rough line-robot channel
- Circle -intersection
- Triangle -robot target point of the internal area

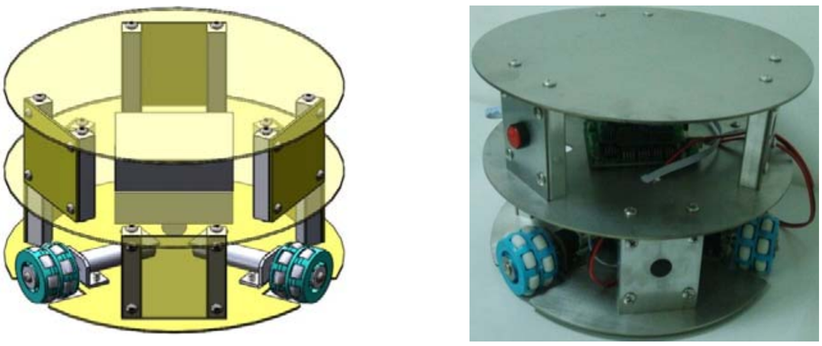


1- Printing Unit; 2- Film laminating Unit;3- Casing-in Unit; 4- Die Cutting Unit;5- Cutting Unit; 6- Folding Unit; 7- Collating Unit; 8- Thread Sewing Unit; 9- Bound Unit;10- Hardcover Unit;11- Adhesive Binding Unit; 12-Flap Unit;13- Saddle Stitching Unit; 14-Knife Trimmer Unit; 15-Wrapping Unit.

Figure 1. Overall layout of the workshop

III. STRUCTURE DESIGN AND MOTION MODEL

After investigation and practice, it is found that the factory layout is usually irregular, which requires the logistics robot to achieve the omni-directional movement, complete the movement pattern of all directions. The study developed a highly mobile robot with the Swedish wheel structure, as shown in figure 2. The robot contains three orthogonal wheels, arranged 120 ° apart, which are installed under the structure of radial symmetry. The following parameters are set as follows: Three wheels are 2 inches in diameter, and include 16 small rollers; The radius of three platforms is all 120mm, while, the radius of the circle of the three wheels is 110mm; the vehicle body height is 180mm.



(a) Structure diagram (b) Experimental prototype

Figure 2. Structure diagram and experimental prototype of omni-directional mobile robot

The robot includes three layers: the bottom layer is the moving layer, the Swedish wheel, the bearing, the coupling, the support frame, the drive shaft, other mechanical moving parts and the drive motor are arranged in the layer. This movement structure belongs to the complete constraint, it can make a straight movement in any direction without the need to rotate in advance; The middle layer is the control layer, the main controller and the motor driver of the robot is arranged in this layer; The upper layer is the carrier layer, the material that needs to be transmitted can be placed on the platform. The three layer platform is designed as a circular, which can make the robot not occupy the space in the process of rotation.

The initial pose of the motion is showed in figure 3, the center of the body is placed in the origin of the coordinate system, and the X axis is coincident with the axis of the wheel 1. Set parameters as follows:

(1). The distance between the wheel and the origin is 1dm.

(2). The initial angles between three wheels and the X axis are 0°, 120°and 240°.

(3). The angles between the coordinate system and body coordinate system are 180°, -60°, 60°.

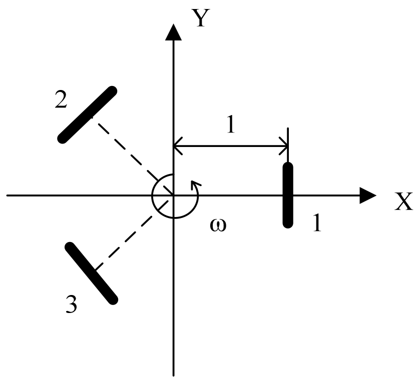


Figure 3. Simple diagram of the initial position

Hence, the inverse kinematic analysis result of the three wheeled omni-directional mobile structure is showed in the formula (1).

$$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} = -\frac{1}{r}\begin{bmatrix} 0 & 1 & l \\ -\frac{\sqrt{3}}{2} & \frac{1}{2} & l \\ \frac{\sqrt{3}}{2} & -\frac{1}{2} & l \end{bmatrix}\begin{bmatrix} v_x \\ v_y \\ \omega \end{bmatrix} \tag{1}$$

The formula (1) shows the relationship between the speed of the three omni-directional wheels and the overall motion pose of the robot. It is the mathematical basis of the robot motion control.

Ⅳ LOCATION

Mobile robot positioning technology[9] generally can be divided into two kinds, namely, absolute positioning and relative positioning. Absolute positioning can directly target coordinates in spatial orientation, which includes the navigation beacon[10], logo positioning[11], graphics matching positioning[12] and GPS positioning[13]. Relative positioning is established by measuring the distance and direction of the robot which is relative to the initial position to determine the robot's current position. Frequently used sensors include the photoelectric encoder[14], mileage meter[15] and inertial navigation system[16]. In this research, we chose the photoelectric incremental encoder for the logistics platform positioning. Incremental optical encoder outputs three sets of pulses, such as phase A, phase B, and phase Z . The phase difference of A and B is 90°, which can be used to determine the direction of wheel rotation. And, the phase Z can be used for the datum point positioning separately. The three encoders are respectively arranged in motor shafts of three universal wheels to realize the rotation at the same speed. So that, we can reverse deduce the robot position by analyzing the movement speed, direction and angle of each encoder.

We assume that the perimeter of driven wheel is L, the encoder coil number is M and the output of pulse number among t is N. And the distance traveled by the wheel during the period of t can be described by the following equation:

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$$\Delta S = \frac{N}{M} L \tag{2}$$

The codes were distributed in the coaxial motors of the omni-directional wheels, by the kinematic analysis above, we can lead to:

$$\begin{aligned} d_x &= \frac{\sqrt{3}}{3} S_1 - \frac{\sqrt{3}}{2} S_2 + \frac{\sqrt{3}}{6} S_3 \\ d_y &= S_1 - \frac{1}{2} S_2 - \frac{1}{2} S_3 \\ \theta &= \frac{1}{2L} S_2 + \frac{1}{2L} S_3 \end{aligned} \tag{3}$$

S1, S2, S3 can be calculated by the encoder data, so the displacement of chassis center, in a system sampling period of dt, can be calculated. Take sample among system operation, we have:

$$\begin{aligned} x_{n+1} &= x_n + d_x \\ y_{n+1} &= y_n + d_y \\ \theta_{n+1} &= \theta_n + d_\theta \end{aligned} \tag{4}$$

Hence, the coordinates and positions of the chassis center can be obtained at every moment, completing chassis positioning in the global coordinate system.

V. PATH PLANNING

Through the literature review, we know that, at present, there are 17 typical algorithms of path planning. And Dijkstra algorithm is the most simple and effective method for the shortest path calculation between two points[17].

The basic thought of Dijkstra algorithm is showed as follows: First, assume that each point has a label, like (Lj, Pj). Leo is the shortest path length from the starting point tothe point j. Pj is the previous point of j in that path; Then, divide all vertices of the graph into two groups L1, L2. The group L1 includes the vertices that have previously been identified. The group L2 includes not yet identified vertices, includes all other vertices other than the source point in the initial time. Finally, calculate the shortest path from the source to the vertices in the sequence of the path length , and add the vertices of the group L2 to L1 one by one , until the point number in the L1 is equal to L2, So as to form a shortest path tree that the root goes from the starting point. The basic flow chart is showed in figure 4.

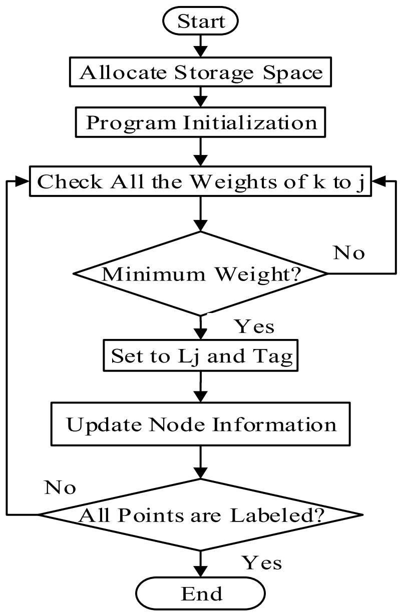

Figure 4. Dijkstra algorithm logic flowchart

VI. NAVIGATION SYSTEM

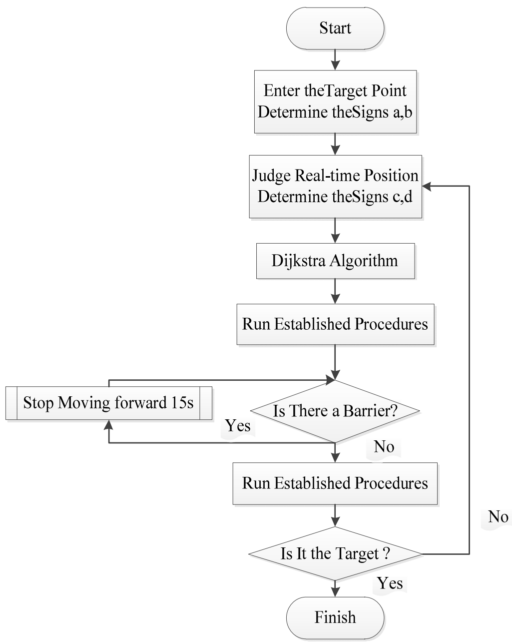

Figure 5. Navigation System

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For autonomous mobile robot, navigation is a difficulty. In the running, the robot always appears wheel slip, idle leading to the robot not reaching the target[18]. Whereas, this paper proposes a navigation system, the logic diagram is showed in figure 5.

According to the process above, the car gets the target information through wireless communication, and determines two crossing signs a, b, through the workshop information early stored, which is in the channel target in. Then, based on the above positioning technology, the real-time position in the global coordinate system, is determined and two signs c, d are determined like a, b. Finally, the shortest distance between the four points is calculated by the Dijkstra algorithm, and the optimal path is chosen to complete the task. During the period, if there is a barrier, the sensor sends a command to stop. Such the cycle until the specified point is reached. This effectively avoids path deflection under the condition such as wheel slippage and idling.

Based on its simple programming and clear results, this research chose the MATLAB platform as the experimental simulation tool, and realized the simulation with the path search from intersection 1to 13. The result is showed in figure 6.

```
function [distance,path]=dijkstra(A,s,e)
……
A=[0,4.6,inf,inf,inf,inf,inf,inf,inf,inf,inf,inf,inf;
……;inf,inf,inf,inf,inf,inf,inf,inf,inf,inf,inf,54.5,0];
s =input('input start point');
e =input('input out point');
[distance,path0] = dijkstra(A,s,e);
fprintf('\n The Min Distance is: %.5f \n', distance);
fprintf('\n The Min Distance path is: \n');
disp(path0);
```

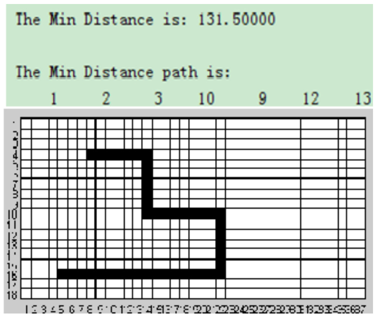

Figure 6. Simulation Process and Result

From the simulation result, it can be seen that the algorithm is very practical and easy toimplement, and can be used in practical application.

Ⅶ. CONCLUSION

The circular omni-directional mobile robot, with a high degree of mobility, can adjust attitude with zero radius turn and move along any predetermined trajectory in the plane without tracking the direction, achieving omni-directional mobility. What's more, it is under a high degree of autonomy, can realize the positioning and path planning in any position. Not only the flexibility and autonomy of the logistics system, but also the operational efficiency and intelligence can be improved. For us, further research is required in the aspects of positioning accuracy, autonomous mobile performance, environmental adaptability and so on .

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