2018 Eighth International Conference on Instrumentation and Measurement, Computer, Communication and Control

The design of indoor mobile robot navigation system based on UWB location

LV Yong
School of electrical engineering
Nantong University
Nantong, China
610087131@qq.com

JIANG Ping
School of electrical engineering
Nantong University
Nantong, China
1728116725@qq.com

***Abstract*—Aiming at the positioning and navigation system of indoor mobile robot, a fuzzy control method of indoor location navigation based on UWB communication technology is proposed. Firstly, based on the UWB radio signal, the mobile robot localization information is obtained by the twice triangular centroid localization algorithm, and the reactive fuzzy controller is used to realize the local path planning. An improved contour following method is proposed to make the mobile robot get out of the trap area quickly and reach the target. This method can effectively drive the mobile robot to reach the target in a complex and unknown environment with reasonable path. Finally, a four-wheel indoor mobile robot is taken as an example in the indoor environment of 10m × 10m. The experiment proves that the method can effectively drive the mobile robot to reach the target point in the unknown environment with the better path.**

Keywords—UWB; positioning navigation; fuzzy controller; improved contour following method

I. INTRODUCTION

Due to the complexity and uncertainty of the indoor environment, the precise positioning and navigation of the mobile robot have been put forward higher requirements in the unknown environment. At present, the commonly used indoor navigation methods are divided into two ways: One is the preset path method, which uses photoelectric, electromagnetic and other technologies to lay wires and spray lead wires on the preset path to realize the function of positioning and navigation. This approach makes the mobile robot control flexibility is not enough, and difficult to achieve multi-robot complex path control. The other is the non-preset path method, which uses laser and visual technology to achieve high cost and is easy to be restricted by environmental factors, and thus it cannot be widely used in the actual industrial scene [1].

As a result of the local path planning based on the sensor information, the reactive navigation method does not need the complete environmental information to improve the real-time and the flexibility of the mobile robot in the unknown environment, and has been widely used [2]. However, due to the lack of understanding of the overall situation, it is easy to make the robot into a local trap. The current effective ways have behavior fusion, sub-virtual goals for this situation. In the document [3], the behavior fusion method is used to solve the problem of tracking the behavior object, but it needs to design the weight of each behavior and make lots of loop tests, which increases the complexity of the system and reduces the applicability of the system. In the document [4], the improved virtual sub-target method is used to solve the problem of path redundancy in complex environment, but its virtual sub-target removal condition is not easy to implement.

This paper proposes a twice triangle centroid localization algorithm to realize the localization of mobile robots based on the Ultra Wide Band (UWB) technique. At the same time, an improved contouring method is proposed to solve the problem that the robot is easy to fall into the local trap. Experiments show that the combination of reactive fuzzy controller and UWB positioning is simple and easy to implement, which improves the behavior initiative and foreseeability of mobile robot and can satisfy the stability and accuracy of mobile robot movement in unknown environment.

II. INDOOR LOCATION BASED ON UWB

Ultra Wide Band (UWB) technology is a non-carrier communication technology with sub-nanosecond ultra-narrow pulse, which has the advantages of high resolution, anti-multipath effect, strong penetrating power and high spectrum utilization. At present, it becomes the best physical layer technology for indoor high-precision positioning and can realize accurate positioning of moving objects [5]-[7].

A. UWB location model

UWB indoor positioning system includes labels, mobile robots and base stations. Among them, the tag is arranged on the mobile robot. The distance between them is calculated by using the TOF (Time of Flight) ranging algorithm. The communication mechanism is shown in Figure 1.

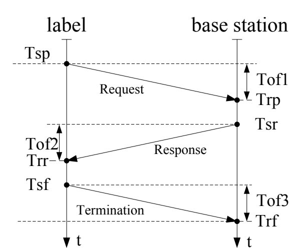


Fig. 1. Tag and base station communication mechanism

Fund Project: Supported by the National Natural Science Foundation of China (61371111).

978-1-5386-8246-3/18/$31.00 ©2018 IEEE
DOI 10.1109/IMCCC.2018.00077

Therefore, the base station can obtain the distance between it and the label:

$$T_{of} = \frac{(T_{rf} - T_{sr}) - (T_{sf} - T_{rr}) + (T_{rr} - T_{sp}) - (T_{sr} - T_{rp})}{4} \quad (1)$$

$$d = T_{of} \times v \quad (2)$$

Where d represents the distance between the base station and the tag, v represents UWB propagation speed.

Due to the presence of signal interference in the indoor environment, the distance between the target and the base station is d, which is greater than the actual distance between two points. As shown in Figure 2, the base station is $O1$, $O2$, $O3$, the target point is D. $d1$, $d2$, $d3$ can be got according to the formula (1-2). Respectively, with its radius, the base station for the circle to draw the circle, the three similarity points A, B, C, then The centroid of $\triangle ABC$ is the coordinates of the target, as shown in equation (3).

$$\begin{cases} x_D = (x_A + x_B + x_C) \div 3 \\ y_D = (y_A + y_B + y_C) \div 3 \end{cases} \quad (3)$$

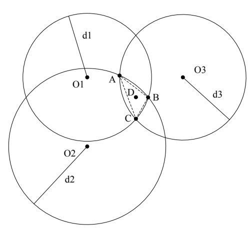


Fig. 2. Triangle centroid algorithm schematic

B. Twice triangle centroid localization algorithm

In the practical application, UWB signal propagation is susceptible to multipath and non-line-of-sight phenomena, and it is difficult to establish a general channel model to estimate the ranging error, so the stability of the algorithm cannot be guaranteed [8].

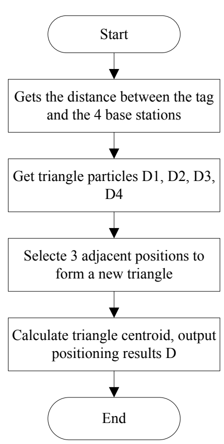


Fig. 3. Twice triangle centroid localization algorithm

In this paper, twice triangle centroid localization algorithm is proposed to improve the accuracy and stability of the algorithm by increasing the number of base stations and weakening the influence of the ranging error. Twice triangle centroid localization algorithm uses four base station distance, adopting any three of these base stations, and obtaining a triangular centroid through the triangular centroid algorithm, a total of four centroids can be obtained, and then construct a new triangle, and recalculate triangular centroid. That is the label position, and the process is shown in Figure 3.

III. Indoor Mobile Robot Control Principle and Model

This paper adopts a typical four wheeled indoor mobile robot, whose front wheels are controlled by steering gear, and the rear wheels are driven by motors. The 5-way ultrasonic sensor is used to detect the distance of the obstacle. In order to avoid the mutual interference between the sensors, ultrasonic sensor timing is shown in Figure 4.

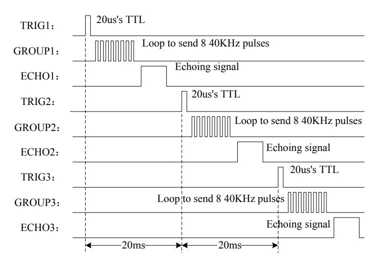


Fig. 4. Ultrasonic cyclic ranging timing diagram

A. Kinematics model

Using the twice triangle centroid localization algorithm to obtain the position information of the mobile robot greatly simplifies the modeling problem of the mobile robot. The focus of the robot modeling is focused on the relationship between the steering angle and the turning radius. According to the theory of kinematics of the car, if the car wheels are rolling without sliding, the wheels must rotate around a central point of Q, the center will fall on the rear axle center line extension line, and left and right front must also be the center of Q is the center of rotation, as shown in Figure 5 [9].

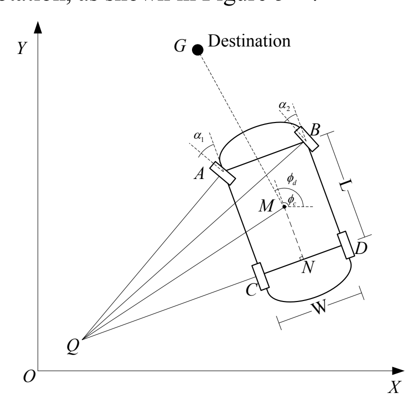


Fig. 5. Kinematic model and attitude state of mobile robot

Therefore, the rotation of the front wheel of the mobile robot should satisfy the following equation:

$$R_{QA} = \frac{L}{sin\alpha_1} \quad (4)$$

$$cot\alpha_2 = cot\alpha_1 + \frac{W}{L} \quad (5)$$

In the formula, R_{QA} represents turning radius, α_1 and α_2 represents left and right wheel angle, W represents track, and L represents wheelbase.

According to the above theory, the center point M makes the arc motion around the rotation center of the wheel when the robot turns. The radius of motion is calculated as shown in equation (6).

$$\begin{aligned} R_{QM} &= \sqrt{(QC+CN)^2 + NM^2} \\ &= \sqrt{(\frac{L}{\tan\alpha_1} + \frac{W}{2})^2 + \left(\frac{L}{2}\right)^2} \end{aligned} \quad (6)$$

Among them, turn left when α_1 >0, turn right when α_1<0.

(x_m,y_m, ϕ) represents the gesture of the mobile robot in the global coordinate system XOY:

$$\phi = \phi_d - \phi_c \quad (7)$$

$$\phi_d = \frac{y_g - y_m}{x_g - x_m} \quad (8)$$

$$\phi_c = \frac{y_m - y_{m'}}{x_m - x_{m'}} \quad (9)$$

In the formula, ϕ_c represents the angle between the robot's motion direction and the X axis, ϕ_d represents the angle between the straight line of the robot and the destination and the axis of the X, (x_m,y_m) are coordinates of the current position for the robot, ($x_{m'}$,$y_{m'}$) are coordinates of the last position for the robot.

B. Dynamics model

The mobile robot performs local path planning based on sensor information and UWB location information. The moving trajectory of robot is tending to the target and excluding the obstacle, so the navigation behavior is divided into the tendency target and the obstacle avoidance, and the rotation angle model and the speed model of the mobile robot are established according to the reference [10].

1) Corner model

The behavior of the mobile robot always tends to the target point and avoids the obstacle. When the robot deviates from the target, the angle should be larger; the angle should be smaller when the target deviates; the closer the obstacle is, the greater the deflection angle. So the rotation of the mobile robot is expressed as:

$$\alpha = \lambda_g \phi + (\lambda_{ob} actan(1/d_{lf} + \varepsilon_0)) \div 2 \quad (10)$$

In the formula, λ represents intensity factor, d_{lf} indicates that the LF and RF sensors for measuring barrier distance differences.

2) Speed model

The speed of the mobile robot is related to the obstacle situation and the target distance. When the robot is far away from the target, the running speed should be larger; when the target is closer, the speed should be smaller; the closer the obstacle, the smaller the speed. So the speed of the mobile robot is expressed as:

$$v = min(k_g d_g, v_{max}, k_{ob} d_{ob} + v_0) \quad (11)$$

d_g indicates the distance from the target, d_{ob} represents the value of the distance barrier, v_{max} represents the maximum speed allowed by the system, k represents intensity factor.

IV. DESIGN OF REACTIVE FUZZY CONTROLLER

Because fuzzy logic has a strong processing power and robustness to the uncertain and incomplete information, the UWB positioning information error is well handled. Therefore, according to the indoor mobile robot model established above, this paper constructs the reactive fuzzy controller. The controller is mainly composed of corner control module and speed control module.

A. Corner control module

The rotation angle of the mobile robot is related to the obstacle condition and the target direction obtained by the ultrasonic sensor.

The basic domain for each detective obstacle distance is [0dm,30dm], the language variable is chosen as two language values: {near (N), far (FA)}. The following eight cases were detected:

TABLE I. OBSTACLE DETECTION SITUATION

LF	F	RF	CASE	LF	F	RF	CASE
FA	FA	FA	Ⅰ	N	FA	FA	Ⅴ
FA	FA	N	Ⅱ	N	FA	N	Ⅵ
FA	N	FA	Ⅲ	N	N	FA	Ⅶ
FA	N	N	Ⅳ	N	N	N	Ⅷ

The basic domain for d_{rf} is [-10dm,10dm], the language variable is chosen as five language values: {middle left (LM), small left (LS), zero (Z), small right (RS), middle right (RM)}.And the basic domain for ϕ is [-180°,180°], the fuzzy set selects five language values: {big left (LB), small left (LS), front (FR), small right (RS), big right (RB)}.

The fuzzy set of output variable θ is {big left (LB), small left (LS), zero (Z), small right (RS), big right (RB)}.

In this paper, all the input and output fuzzy amount membership function definition as shown in Figure 6.

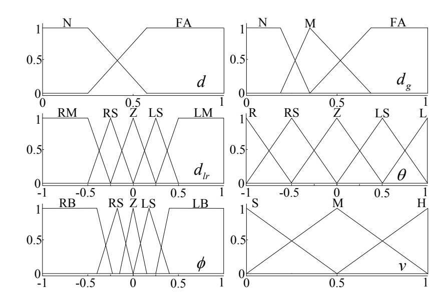


Fig. 6. The membership function of input and output

According to formula (6) and (10), the angle fuzzy control rules are set as shown in table 2.When the obstacle condition is detected as *CASE VIII*, the rotation angle of the robot is related to its position and target direction, so the establishment of corner fuzzy control rules is shown in Table 3.

Using Mamdani reasoning mechanism to solve the fuzzy, get the robot's corner control:

$$\theta = \frac{\sum_{i=1}^{n} w_i u(x_i)}{\sum_{i=1}^{n} u(x_i)} \tag{12}$$

$$\overline{\theta} = k\theta \tag{13}$$

w_i represents the weight of rule *i*, $u(x_i)$ represents the center of the fuzzy set of clause *i* rules, n represents the total number of rules, θ indicates the clear value of the output corner, formula (13) indicates the actual rotation of the mobile robot, *k* represents the scale factor(k= 180).

TABLE II. FUZZY RULE SET 1 OF CORNER CONTROL

θ		ϕ				
		LB	LS	FR	RS	RB
CASE	I	L	LS	Z	RS	R
	II	L	LS	Z	Z	Z
	III	L	LS	L	RS	R
	IV	L	LS	L	L	L
	V	Z	Z	Z	RS	R
	VI	Z	Z	Z	Z	Z
	VII	R	R	R	RS	R

TABLE III. FUZZY RULE SET 2 OF CORNER CONTROL

θ		ϕ				
		LB	LS	FR	RS	RB
d_{lr}	LM	L	L	L	L	L
	LS	L	L	L	R	R
	Z	L	L	L	R	R
	RS	L	L	R	R	R
	RM	R	R	R	R	R

B. Speed control module

The speed of the mobile robot is related to the obstacle condition and the distance between the target and the target.

The basic domain of apart from the target is [0*dm*,150*dm*] (assuming the indoor environment is 100*dm**100*dm*), then k_{dg} = 1/150 (k_{dg} is the quantization factor of the target distance d_g), the language variable is chosen as three language values: {near (N), middle (M), far (FA)}.

The fuzzy set of output variable v is {slow (S), middle speed (M), high speed (H)}.

According to the formula (11), the rules can be formulated as shown in Table 4, which takes into account the smooth movement of the robot from the beginning of the origin to the end of the target and the safety of the middle.

TABLE IV. FUZZY RULE SET OF SPEED CONTROL

v		d_g		
		N	M	FA
CASE	I	S	M	H
	II	S	M	M
	III	S	M	M
	IV	S	M	M
	V	S	M	M
	VI	S	M	H
	VII	S	M	M
	VIII	S	S	S

Using the Mamdani inference mechanism, the speed control of the robot is obtained:

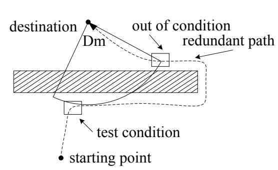
$$v = \frac{\sum_{i=1}^{n} w_i u(x_i)}{\sum_{i=1}^{n} u(x_i)} \tag{14}$$

$$V = \frac{v_{max} + v_{min}}{2} + k(v - \frac{1}{2}) \tag{15}$$

In the formula, w_i represents the weight of rule *i,* $u(x_i)$ represents the center of the fuzzy set of clause *i* rules, *n* represents the total number of rules, *v* indicates the clear value of the output speed, *V* indicates the actual running speed of the mobile robot, *k* represents the scale factor(k = v_{max}-v_{min}), [v_{max},v_{min}] represents the range of actual speed change.

C. Improved contour followment method

The documents [11] uses contour tracing method to solve the problem of trap, but from the current condition of target distance is less than the detection condition D_m the target distance is not timely recovery of actual target, leading to redundant path of motion, as shown in Figure 7. Therefore, this paper presents a contour follower method based on UWB and ultrasonic sensor. The basic idea is to use 1 or 5 sensor information to keep the robot at a certain distance from the obstacle and move along the contour of the obstacle. At the same time, the obstacle condition in the target direction is detected continuously. When there is no obstacle in the target direction, the position is taken as the new starting point, and the object is moved away from the obstacle and toward the target. When the target has an obstacle, the robot continues to move along the contour of the obstacle, as shown in Figure 8.



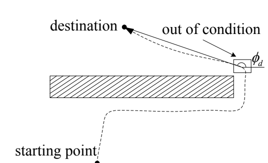


Fig. 7. The contour following method in [11] (left)

Fig. 8. Improved contour following method (right)

V. EXPERIMENTAL RESULTS AND ANALYSIS

The experimental environment adopted in this paper is an indoor 10*m* × 10*m* industrial workshop. 4 base stations are arranged in the four corners of the workshop, and the base station coordinates are (0,0), (0,10), (10,10) and (10,0), the base station height is 4m, and the target point coordinate is

(8,8). The mobile robot and the base station communicate with each 4ms once and each 0.5s is positioned once. The fuzzy control algorithm described above is implemented on a four-wheel mobile robot based on the STM32F104Z, as shown in Figure 9.

Fig. 9. Mobile robot prototype

The data of robot movement are collected by wireless transmission, and 10 positions are selected. The triangle centroid algorithm and the four point two centroid algorithm are used to compare experiments, as shown in table 5. It can be seen that the improved triangular centroid algorithm significantly improves the accuracy of positioning. The average error is reduced by 9cm. Further, all the positioning data in the movement of the mobile robot is recorded, and the motion trajectory is drawn. The experimental results are shown in Figures 10-11.

TABLE V. POSITIONING ERROR COMPARISON

actual position coordinate (*m*,*m*)	**triangle centroid algorithm (*m*)**	**twice triangle centroid algorithm (*m*)**
(2,5)	0.26	0.19
(4,4)	0.19	0.11
(6,8)	0.24	0.17
(8,9)	0.37	0.26
(5,5)	0.18	0.09
(2,8)	0.29	0.20
(3,9)	0.35	0.23
(8,5)	0.23	0.12
(7,2)	0.28	0.21
(9,3)	0.33	0.24
average error (*m*)	0.272	0.182

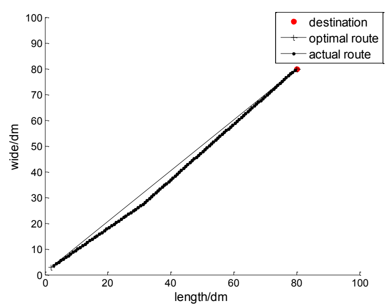


Fig. 10. Trajectory without barrier

Figure 10 shows the trajectory of the robot in the absence of obstacles. The trajectory is basically consistent with the optimal route, and can be stable and stable, which meets the requirements of positioning and navigation of mobile robot in the actual workshop environment.

Figure 11 reflects the trajectory of the robot in the presence of an obstacle. It can be seen that, at the beginning, the mobile robot moves along the target direction, moves along the obstacle when it meets the obstacle, and gets out of the obstacle at the right time. At the same time, the effectiveness of the improved contour following method is illustrated. Compared with the optimal route, because the sensor perception range is limited, the route optimization is not enough, but it can still reach the destination quickly and accurately, and realize the localization and navigation of the robot.

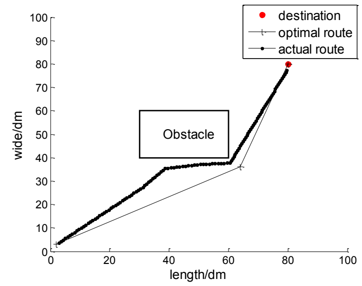


Fig. 11. Trajectory with barrier

VI. CONCLUDING REMARKS

In this paper, a fuzzy controller is designed to make the robot run smoothly, accurately and safely in an unknown indoor environment. The improved contour following method and the twice triangle centroid localization algorithm are proposed. The UWB positioning is used to optimize the separation conditions and reduce redundant paths. In a more complex environment, it can also be well adjusted. The experimental results show that the system designed in this paper is feasible and practical.

REFERENCES

[1] Hu K W. Research on Navigation and Obstacle Avoidance Technology of AGV Navigation [D]. Hangzhou: Zhejiang University, 2012:2-5.

[2] Cai Z X, He H G, Chen H. Research on navigation control of mobile robot in unknown environment [J]. Control and Decision, 2012, 17(4):385-490.

[3] Hu C H, Ma X D, Dai X Z. Behavior based mobile robot target tracking control method [J]. Control Engineering, 2011, 18(2):318-321.

[4] Liu H L, Luo Y Y, Li C R. Mobile Robot Navigation in Unknown Environment Based on Fuzzy Controller [J]. Computer Simulation, 2011, 28(1):201-205.

[5] Guo J G, Deng Z W, Yang R E. A New Algorithm for UWB Location Based on Improved Variable Scale Method [J]. Computer Application, 2014, 34(12):3395-3399.

[6] MONICA S, FERRARI G. A swarm-based approach to real-time 3D indoor localization: experimental performance analysis [J]. Applied Soft Computing, 2016, 43:489-497.

[7] Wei P, Jiang P, He J J, Zhang H M. Localization of UWB indoor based on inner triangle centroid algorithm [J]. Computer Application, 2017, 37(1):289-293,298.

[8] Fan F H, Ruan H L. Non convex compressed sensing ultra wideband channel estimation method at low signal-to-noise ratio [J]. Journal of Electronics, 2014, 42(2):353-359.

[9] He F, Yang N. Vehicle dynamics [M]. Guiyang: Guiyang science and Technology Press, 2003:50-53.

[10] Zhang H D, Liu S R, Yu J S. Behavior design of autonomous mobile robot based on dynamic system approach [J]. Journal of East China University of Science and Technology (Natural Science Edition), 2008, 34(6):843-849.

[11] R Chatterjee, F Matsuno. Use of single side reflex for autonomous navigation of mobile robots in unknown environments [J]. Robotics and Autonomous Systems, 2001, 35(2):77-96.