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Fuzzy Control of Intelligent Tracing Vehicles

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Abstract: As the technology of the intelligent tracing vehicles is developing, demands on high performance intelligent tracing vehicles are increasing. Using proper control methods can significantly improve the quality of intelligent tracing vehicles. By studying the working principles of tracing vehicles, relationships among their speeds, angular speeds and driving motor speeds are derived. Also, front, medially and back symmetrical tracing sensor arrays are also designed. Meanwhile, a fuzzy control algorithm is proposed to recognize the motion paths. The proposed fuzzy control method can achieve the tracing purposes of the tracing vehicles. It is verified by experiments. The tracing vehicles can travel along the lines with small radians and can even fulfill right-angle turnings in addition to walking on straight lines and the lines with large radians.

Key words: Tracing, vehicle, intelligent, fuzzy control, sensor

INTRODUCTION

Similar to typical mechantronic systems, intelligent vehicles integrate their mechanical systems, power systems, intelligent control systems and path recognition systems together (Rong-Ben *et al*., 2006; Huang *et al*., 2009; Xiafu and Yong, 2009; Nan *et al*., 1999). Furthermore, there are important applications to modern transportations, modern logistics and unmanned factories, etc. (Demirli and Khoshnejad, 2009; Bernt, 2006). Therefore, their designs and applications, etc., attract many attentions. To achieve the normal, fast and reliable operations of intelligent vehicles, control based on sound performances is indispensable. This is because it is essential for vehicle positioning, navigation and path planning. As the demands on high performances of intelligent vehicles are increasing, more requirements on the timeliness, stability, accuracy and robustness of the controlled systems are imposed. However, since the intelligent vehicles are nonlinear complex systems, it is difficult to establish accurate mathematical models and traditional control methods are also not competent. On the other hand, fuzzy controls are nonlinear control methods which do not require object mathematical models with good robustness. Hence, they can be employed for controlling intelligent vehicles based on sound performances (Hessburg and Tomizuka, 1994). In order to realize intelligent tracing vehicles along a predetermined trajectory stability and rapid movement, in the study, input (tracing sensor) and output (motor rotation speed and direction) of intelligent vehicles are fuzzified and the proper fuzzy rule is established.

WORKING PRINCIPLES OF INTELLIGENT TRACING VEHICLES

As shown in Fig. 1, an intelligent tracing vehicle consists of the body, motor, controller, motor driver, sensor, battery and some connecting elements. Its body is made of rectangular (300×220 mm) stainless steel. Other parts of the vehicle are connected to the body with the connecting elements. The tracing vehicle is equipped with two DC motors. The DC motors are operating at 12V DC. The output drives two shafts in which with their directions are the same. The rotational speeds are obtained by the reducer. A wheel is installed at each output end. When the motor is rotating, it can be guaranteed that the two wheels are rotating with the same speed and the same direction. The four wheels of these two motors are symmetrically placed in the tracing vehicle. The tracing vehicle with this structure is relatively stable. The chargeable lithium battery is placed at the center line of the body. The battery drives the two DC motor driver modules (L298) with each module consisted of one single motor. The body is symmetry to ensure the said structure. Also, the body center and the gravity center are overlapped which is easy for the motional control. The controller is placed at the top right corner of the battery to facilitate the connection among different parts of the vehicles and the download program. In Fig. 2, the circles

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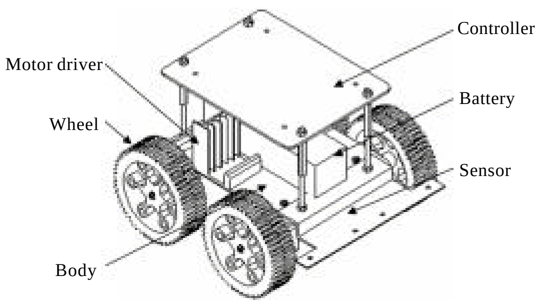

Fig. 1: Structural diagram of an intelligent tracing vehicle

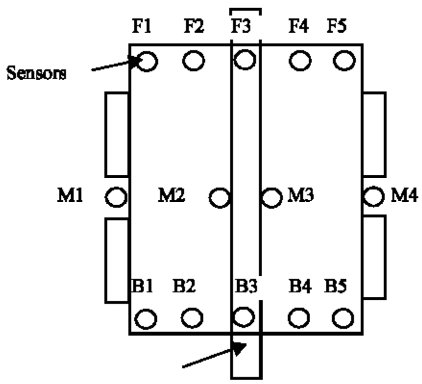

Fig. 2: Layout of the sensors of an intelligent tracing vehicle

represent the locations of the tracing sensors. The sensors are placed at the front, middle, back rows of the body. There are five tracing sensors at the front and back rows of the body, two sensors near the body center in the middle row and one sensor at the middle, left and right wheels of the body. In total, there are 14 sensors. The tracing vehicle moves along the white band with the width being 20 mm. This white band is stuck to ground and with a dark color such as green or black color etc. The tracing sensor of the vehicle consists of a high-intensity Light Emitting Diode (LED) and a photosensitive diode. When the vehicle moves on the white band, the high-intensity LED of the tracing sensor of the vehicle will emit high-intensity optical signals and many signals will be received by the photosensitive diode via the reflection of the white band. Once the optical signals are received, the photosensitive diode will be conducted and the signals corresponding to ‘1’ will be outputted by the sensor conditioning circuit. If it is not on the white band, then the photosensitive diode will only receive a small amount of optical signals. Finally, it will be closed and the sensor will output the signal corresponding to ‘0’.

As shown in Fig. 2, the distance of the edges between two adjacent circles is 30 mm where the diameter of the small circle is about 10 mm. The distance between the sensor and the ground is 20 mm. Since the tracing vehicle is designed with the front/back symmetrical structure, it can be moved both forward and backward. When it moves forward, the sensor F1-F5 at the front row as well as the middle sensors M2 and M3 will be taken effect. When it moves back, the sensors B1-B5 at the back row as well as the middle sensors M2 and M3 will be taken effect. Only one front/back sensor can be used for detecting the white band during the normal tracing. The middle sensors M2 and M3 are used for stabilizing the vehicle. When the band is turning with a small radian, the M1 and M4 sensors will be used for detecting the white band. This enhances the intelligent tracing capability of the vehicle. When the tracing vehicle moves forward, if the F3 sensor detects the white band while the middle sensor fails to detect it, then the vehicle will move at the full speed. If the sensors F1 or F2 and M2 or M3 detect the band, then the vehicle will move to the right direction. This results to the leftward adjustment. Moreover, the range of the adjustment will be determined by the individual situation of the deviation. Similarly, if the sensors F4 or F5 and M2 or M3 detect the band, then the rightward adjustment is required for the vehicle. The principle of the backward motion of the tracing vehicle is the same as that of the forward motion.

Motion of the tracing vehicle is determined by the direction and the speed of these two left/right drive motors. The ground motion of the vehicle can be categorized into linear and rotating motions. Under the Cartesian coordinate system, the gesture, speed and angular speed of the tracing vehicle are represented by (x, y, θ, v, ω). The motion equation (Demirli and Khoshnejad, 2009) of the robot is governed by the following:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{1}$$

According to the Eq. 1, the gesture of the tracing vehicle is controlled by its linear speed and its angular speed. However, the linear speed and the angular speed cannot be directly used for control. The linear and the angular speed of the vehicle must be controlled by the direction and the speed of the drive motor. As shown in Fig. 3, the dual wheel differential drive mode is employed for controlling the vehicle. The relationship between the leaner and the angular speed of the robot as well as the speed of these two drive motors are as follows:

$$\omega = \frac{V_R - V_L}{2 \times L_2} \tag{2}$$

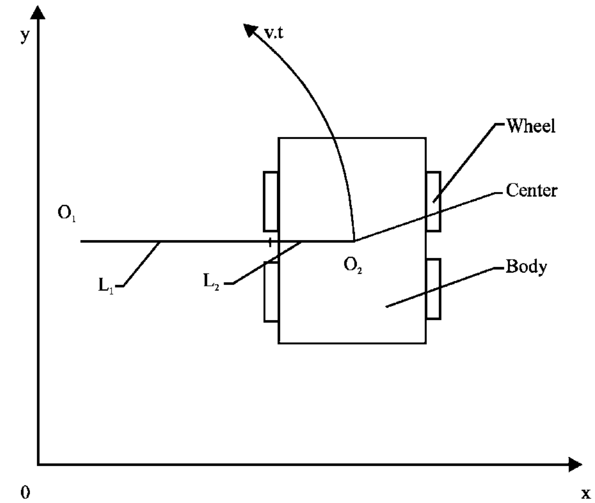

Fig. 3: Diagram of the motion of an intelligent tracing vehicle

$$V = \frac{V_R + V_L}{2} \tag{3}$$

Where:

- V = The motional speed of the center of mass (i.e., center) of the vehicle
- V_L = The motional speed of the left wheel
- V_R = The motional speed of the right wheel
- L_1 = The distance between the left Fuzzy Control
- L_2 = The half of space between these two wheels
- ω = The angular speed of the center of mass of the tracing vehicle
- O_1 = The center of rotation of the tracing vehicle
- O_2 = The center of mass of the vehicle

FUZZY CONTROL

Defined variables: The inputs of the intelligent tracing vehicle include the front (F1-F5), middle (M1-M4) and back (B1-B5) tracing sensors as well as its outputs are two motors. There are in total 14 sensors. To analyze the working principle of the tracing vehicle, according to Eq. 2 and 3, the control of the speed of the tracing vehicle and the angular speed can be via only by the motor speed. Thus, the gesture control of the tracing vehicle can be realized. Since the control procedures for the forward and backward motions of the vehicle are the same, this study mainly discusses on the forward motion.

Fuzzification: These five front sensors of the tracing vehicle are served as an input variable for the fuzzification. The fuzzy domain is chosen as (-2, 2). The fuzzy variables correspond to five grade names denoted

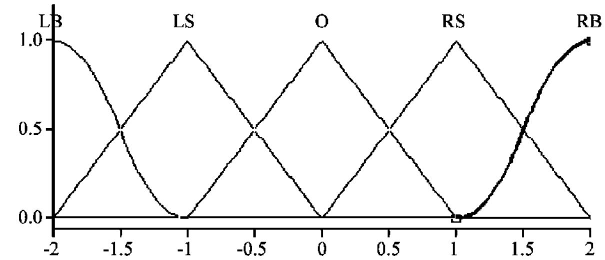

Fig. 4: Membership functions of the front and middle sensors as well as of the angular speed

as "-2", "-1", "0", "1" and "2". These five grade names correspond to five fuzzy subsets defined by their membership functions. By using the fuzzy variable assignment technique, the fuzzy variables with the symbols "LB", "LS", "O", "RS" and "RB" are used to express the sensors F1-F5. These membership functions are shown in Fig. 4. The abscissa is fuzzy domain (-2, 2), the ordinate is the membership of (0, 1). Here, the symbols "LB" and "RB" are governed by the Z-type and the S-type membership functions, respectively. The remaining symbols are governed by the triangle membership functions.

These four middle sensors are also employed as the input variable for the fuzzification. By using the zero detection of these four sensors as an input variable, the fuzzy domain is also chosen as (-2, 2). The fuzzy variables correspond to five grade names denoted as "-2", "-1", "0", "1" and "2". These five grade names correspond to five fuzzy subsets defined by their membership functions. By using the fuzzy variable assignment technique, the fuzzy variables with the symbols "LB", "LS", "O", "RS" and "RB" are used to express the sensors M1, M2, Zero, M3 and M4. These membership functions are shown in Fig. 4. Here, the symbols "LB" and "RB" are governed by the Z-type and S-type membership functions, respectively. The remaining symbols are governed by the triangle membership functions.

For the speed and the angular speed used for controlling the gesture of the tracing vehicle, the grade units are also employed for describing the controlled variable domain. Here, the angular speed is in the range (-2, 2) and the speed is in the range (0, 4). The fuzzy subsets of the angular speed are "LB", "LS", "O", "RS" and "RB". It refers to "Left Big", "Left Small", "Zero", "Right Small" and "Right Big". These membership functions are shown in Fig. 4. The abscissa is fuzzy domain (-2, 2), the ordinate is the membership of (-1, 1). The symbols "LB" and "RB" are governed by the Z-type and S-type membership functions, respectively. The remaining are triangle membership functions. Since the

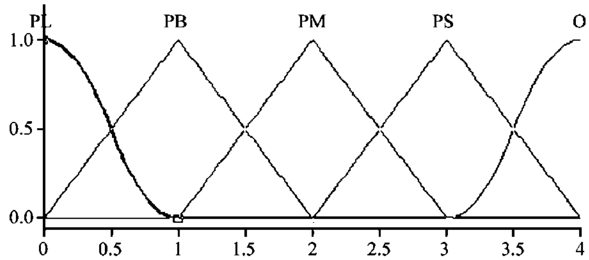

Fig. 5: Membership function of the speed

speed only has one direction, the fuzzy subsets correspond to "O", "PS", "PM", "PB" and "PL". Practically, it refers to "Pace is zero.", "Pace is small.", "Pace is middle.", "Pace is big." and "Pace is large". These membership functions are shown in Fig. 5. The abscissa is fuzzy domain (0, 4), the ordinate is the membership of (0, 1). The symbols "PB" and "O" are governed by the Z-type and S-type membership functions, respectively. The remaining symbols are governed by the triangle membership functions.

Fuzzy control rules: Six overall empirical rules for the control of the tracing vehicle are obtained by the experts' theoretical knowledge and practical experiences:

- If the vehicle moves to left, then the angular speed is clockwise
- If the vehicle moves to right, then the angular speed is counterclockwise
- If the vehicle is oversized, then the speed is small
- If the vehicle is undersized, then the speed is large
- If M1 is detected, then the speed is zero and the angular speed is counterclockwise
- If M4 is detected, then the speed is zero and the angular speed is clockwise

The front and back sensors will determine whether the tracing vehicle moves to left or right and is whether oversized or undersized. The directions of the angular speed are shown in Fig. 3. This is used to judge whether it is clockwise or counterclockwise. The corresponding control rules are described via the fuzzy condition statements as below:

IF F = LB AND M = LB THEN ω = LB
IF F = LB AND M = LS THEN ω = LS
IF F = LB AND M = O THEN ω = LB

...
...

Table 1: Control rules of front, middle sensors and angular speed of vehicles

		Middle sensors				
Angular speed		M1	M2	Zero	M3	M4
Front sensors	F1	LB	LS	LB	LB	RB
	F2	LB	O	LS	LB	RB
	F3	LB	RS	O	LS	RB
	F4	LB	RB	RS	O	RB
	F5	LB	RB	RB	RS	RB

Table 2: Control rules of front, middle sensors and speed of vehicles

		Middle sensor				
Speed		M1	M2	Zero	M3	M4
Front sensors	F1	O	PB	PM	PS	O
	F2	O	PL	PB	PM	O
	F3	O	PB	PL	PB	O
	F4	O	PM	PB	PL	O
	F5	O	PS	PM	PB	O

IF F = RB AND M = RB THEN V = O
IF F = RB AND M = RS THEN V = PM
IF F = RB AND M = O THEN V = PB

...
...

Overall, all these 25 rules for controlling the direction of the vehicle can be simplified using a fuzzy control rule table as shown in Table 1. All these 25 rules for controlling the speed of the vehicle can be simplified using a fuzzy control rule table as shown in Table 2. Refer to Table 1, 2 and Fig. 2, the tracing vehicles angular velocity and speed value are determined according to the former, in tracing sensor distribution, so as to make vehicles tracing.

The diagram showing the relationship of the rules for the angular speed and the speed as well as for the front and the middle sensors are shown in Fig. 6 and 7, respectively. As shown in the figures, when M1 is detected, the tracing vehicle rotates counter clock wisely with "PL" and its forward speed is zero. This indicates that the tracing vehicle rotates along the center with a small radian. Similarly, when M4 is detected, the tracing vehicle rotates clock wisely. When tracing the straight line or the line with a large radian, the M2, M4 and front sensors are taken effect for rectifying the gesture deviation. When the gesture of the tracing vehicle is oversized, the angular speed will increase and the speed will decrease simultaneously. This is useful for adjusting the gesture quickly. When the gesture is stable, the angular speed is possibly small and the speed is possibly large. This is useful for increasing the speed of the tracing vehicle.

Defuzzification: Compute the maximum value among the output fuzzy values and multiply it by a quantifying factor

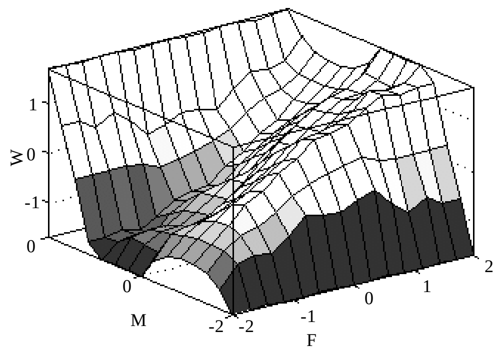

Fig. 6: Diagram of the relationship of the rules of the angular speed as well as the front and middle sensors

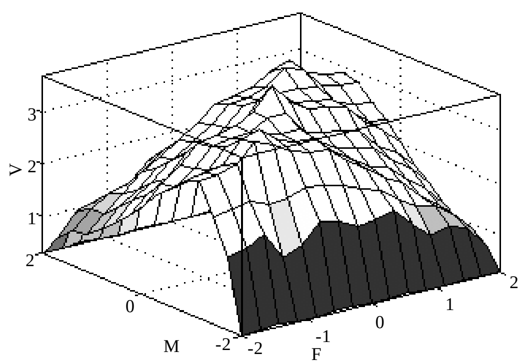

Fig. 7: Diagram of the relationship of the rules of the speed as well as the front and middle sensors

(For the speed, the factor is equal to 0.1. For the angular speed, the factor is also equal to 0.1.) so that an accurate value is obtained. Then, the specific speed value of the left/right motors is obtained according to Eq. 2 and 3 for controlling the gesture of the robot. Thus, the tracing purpose is achieved.

Tests: The constructed intelligent tracing vehicle platform is shown in Fig. 8. Choose the length of the white band as 2 m. It is used to test the straight line, the line with a large radian and the turning of the right angle (1 m before or after the turning).

The tracing vehicle is located at a position shown in Fig. 2 before it departs. It takes 6, 15 and 10 sec to walk on a 2 m long straight line, a line with a large radian and to complete the turning of the right angle, respectively.

The speed is faster when the vehicle is walking on the straight line. The nearly vehicle moves forward intermediately with the full speed only by twice minor adjustments as shown in Fig. 9a. Nevertheless, the tracing

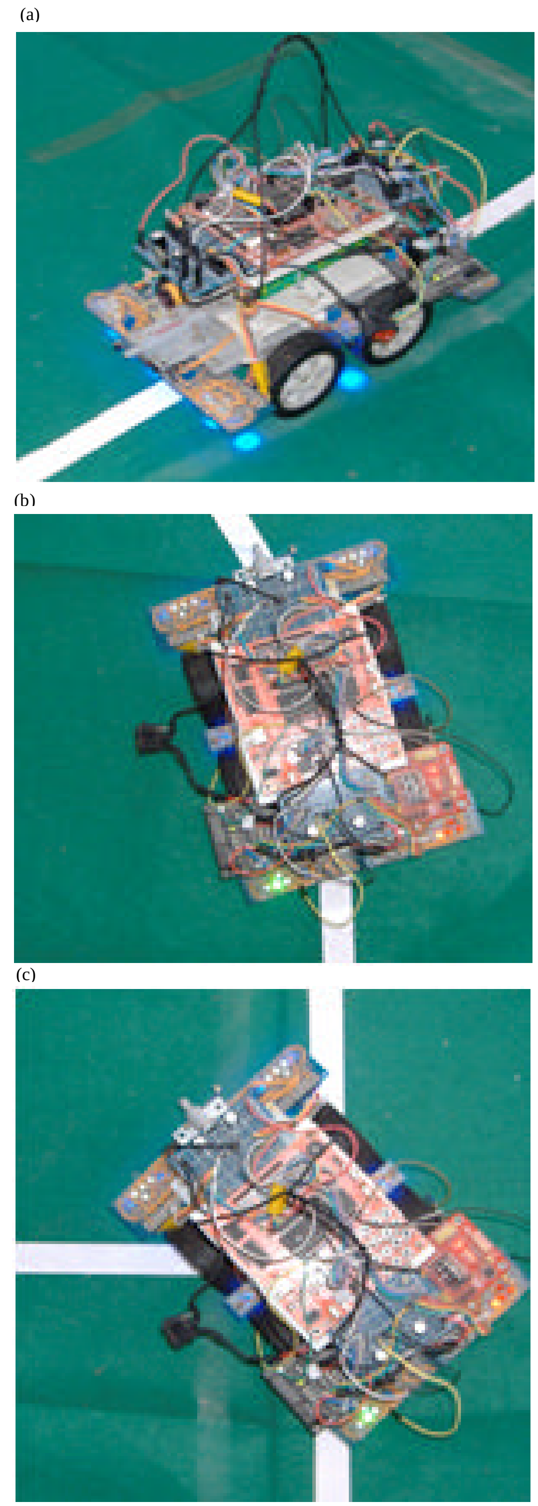

Fig. 8(a-c): Test photos of the tracing vehicle. (a) Straight line, (b) Line with a large radian and (c) Turning of a right-angle

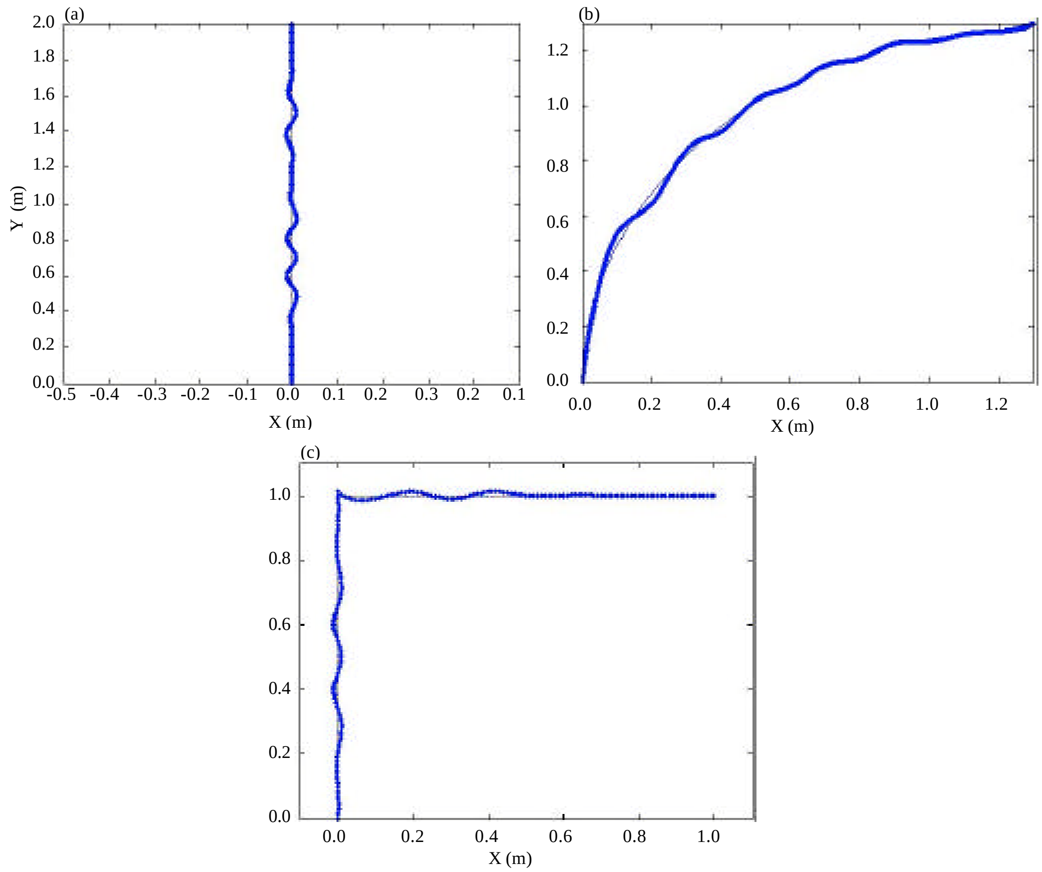

Fig. 9(a-c): Diagram of the tracing vehicle center. (a) Straight line, (b) Line with a large radian and (c) Turning of a right angle

vehicle cannot realize the holosymmetry since there is a minor difference between the frictions of two wheels. Therefore, there is less deviation after moving 0.4 m. When the vehicle walks on a line with a large radian, the tracing vehicle moves using a medium to low speed via the ceaseless adjustment for the gesture. Thus, it takes the longest time.

As shown in Fig. 9b, the vehicle moves along a straight line at the beginning. When the deviation of the vehicle and the white band becomes bigger, the vehicle speed slows down for adjusting the gesture. Later, the vehicle is in the motional state for the wavy adjustment.

When passing the turning of the right angle, the vehicle will rotate at the turning point and then continue to trace. Other aspects in the turning of the right angle are the same as those of the straight line travel. The only difference is that it takes a certain time for turning. As shown in Fig. 9b, when the vehicle arrives at the right-angle point, the center crosses the point because of the inertia. This results to the deviation of the vehicle and the white band after the turning. Then, there is an adjustment process. Thus, the vehicle takes a longer time.

CONCLUSION

- The intelligent tracing vehicle is designed. It consists of 14 tracing sensors and 2 left/right motors. The working principle is also analyzed for developing a control method
- The fuzzy controller is designed based on the characteristics of the tracing vehicle
- The fuzzy control method based on testing results is used for achieving the tracing purpose of the vehicle. The vehicle can travel along the line with a small radian and can even fulfill the turning of the right angle during walking on a straight line and a line with a large radian

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