Chapter 5
Human Following Techniques by Indoor Autonomous Vehicle

5.1 Introduction

After a person's face is detected, the system will learn the color of the person's clothes before following him/her. However, if the followed person turns fast at a corner, the system will lose the track of the person. We propose a method to solve this problem in this study. We find that the disappearing person usually may be found at the crossroad by looking at the direction in which he/she disappears. Therefore, we design the system to learn the crossroad points in the environment in advance. Furthermore, when the person disappears in the view of the vehicle, we design the system to record, with help of the image taken by the camera in the robot arm, immediately the last position of the person as well as on which side with respect to the vehicle (to the left or right of the vehicle) the person was. The system will then use such recorded information to command the vehicle to move a correct crossroad point and turn to the correct direction to search the disappearing person in the image views taken subsequently.

In addition, the vehicle will adjust its orientation for monitoring the surrounding when it follows the person. Therefore, if the person walks in a narrow path, the vehicle will not hit the wall. In Section 5.3, we will describe the details of the above-mentioned techniques. In Section 5.2, we will give a brief introduction to the human following process.

5.2 Proposed Process of Human Following

In the previous chapter, we describe how to detect the face of a person. Then in the process of human following, the vehicle follows the person by detecting the clothes of the person consecutively. If the system cannot detect the person for a while, the person is considered to make a fast turn at a corner. The system will then enter the turning mode to search the disappearing person. In the turning mode, the system will use the crossroad points and the images captured by the robot arm camera to walk to the correct crossroad position and turn to the right direction in which the disappearing person walked. The detailed process of human following is described in the following as an algorithm. An illustration of human following is shown in Figure 5.1.

Algorithm 5.1 *Process of human following*.

Input: Current image I_c.

Output: The result of a person's detection.

Steps:

Step 1. Detect the clothes of the followed person in I_c.

Step 2. If the person's clothes are detected successfully, go to Step 6; else, go to the next step to enter the turning mode.

Step 3. Guide the vehicle to walk to the correct crossroad-point by using information of the crossroad points.

Step 4. Turns to the correct direction for searching the followed person by the information of the images captured by the robotic arm camera.

Step 5. If the followed person is detected, go to Step 1; else, stand here and wait.

Step 6. Compute the distance by the angular mapping.

Step 7. If the vehicle is too close to the person, use the area tracking technique to follow the person;

else

if the person stand at an identical position, the vehicle will enter the human interaction process;

else guide the vehicle to go forward to avoid losing the information of the person.

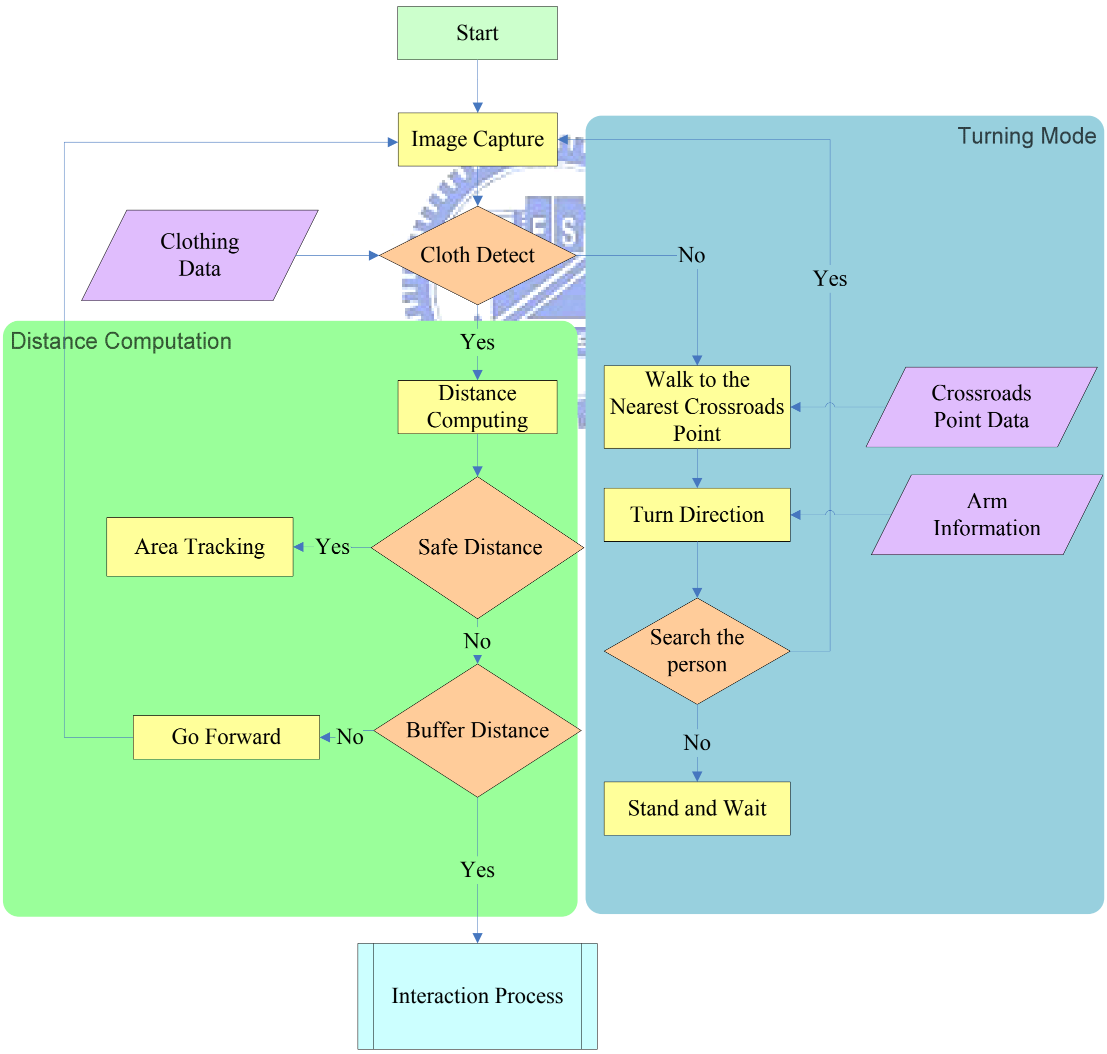

Figure 5.1 An illustration of the human following process.

5.3 Fast Human Turning at A Corner in A Narrow Path

When the person turns fast at a corner in a narrow path, it is difficult for the vehicle to keep following the person. In this section, we propose a method to solve this problem. In Section 5.3.1, we will describe the method for guiding the vehicle to the correct crossroad where the person disappears. Then the vehicle will use the arm's camera view information to measure the direction where the disappearing person turns to. By using the information of the arm and adjusting the orientation of the vehicle which is mentioned in Section 3.4.3, the vehicle can avoid hitting the wall in a narrow path. We will describe the ideas involved in this method in Section 5.3.2. An illustration of the turning mode is shown as follows:

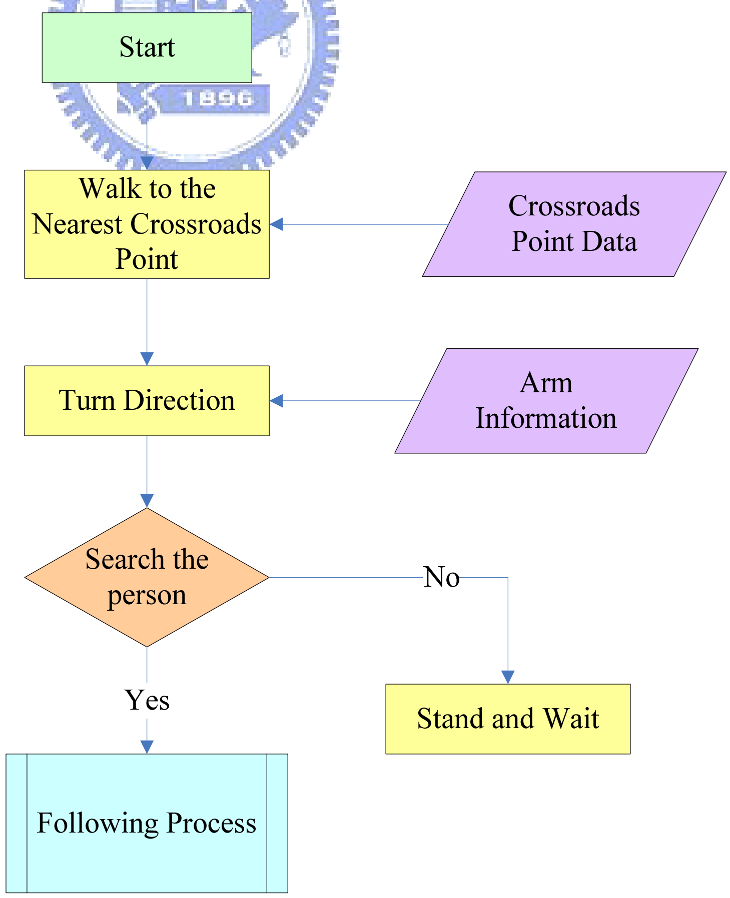

Figure 5.2 An illustration of the turning mode.

5.3.1 Adaptation to fast turning by crossroad points

In the learning process which was introduced in Section 2.3, the vehicle learns the crossroad points when it is in a new environment, like the red points illustrated in Figure 5.3. So if the person disappears for a while, the vehicle can use these points to search the person. To choose the correct points from these crossroad points, the system always has to record the position of the person in the real world. Then once the person disappears, the system can find the crossroad point nearest to the last position of the person. For example, the crossroad point 2 will be found for the case shown in Figure 5.4. The detail of the proposed method is described in the following as an algorithm.

Algorithm 5.2 *Adaptation to fast turning*.

Input: The current image I_c, a reference image I_r, the disappearance time T of the person, a crossroad point set $P_{cross} = \{P_{c1}, P_{c2}, \ldots, P_{cn}\}$, the distance between the vehicle and the followed person D_{last}, the position (W_{vx}, W_{vy}) of the vehicle in the real world and the position (W_{px}, W_{py}) of the person in the real world.

Output: Command the vehicle to go forward to the correct crossroad point, ($Cross_x$, $Cross_y$).

Steps:

Step 1. Detect the person in the reference image I_r.

Step 2. Measure the distance between the vehicle and the person D_{last}.

Step 3. Measure the position of the person in the real world by Eqs. (3.10) and (5.2) as follows:

$$W_{px} = W_{vx} + D_{last} \cdot Sin\theta; \quad (5.1)$$

$$W_{py} = W_{vy} + D_{last} \cdot Cos\theta \,. \tag{5.2}$$

Step 4. Detect the person in the current image I_c. If the person is detected, set the I_c as I_r. and go to Step 1; else, compute the disappearance time T of the person. If T is larger than 3 seconds, go to Step 5; else repeat Step 4.

Step 5. Let (P_x, P_y) denote the values of $P_{cross\ ij}$. Find out the point, ($Cross_x$, $Cross_y$), from crossroad point set P_{cross}, which is nearest to the point (W_{px}, W_{py}) by Eq. (5.3) below:

$$D = \sqrt{(W_{px} - P_x)^2 + (W_{py} - P_y)^2} \,. \tag{5.3}$$

Step 6. Command the vehicle go to the point, ($Cross_x$, $Cross_y$).

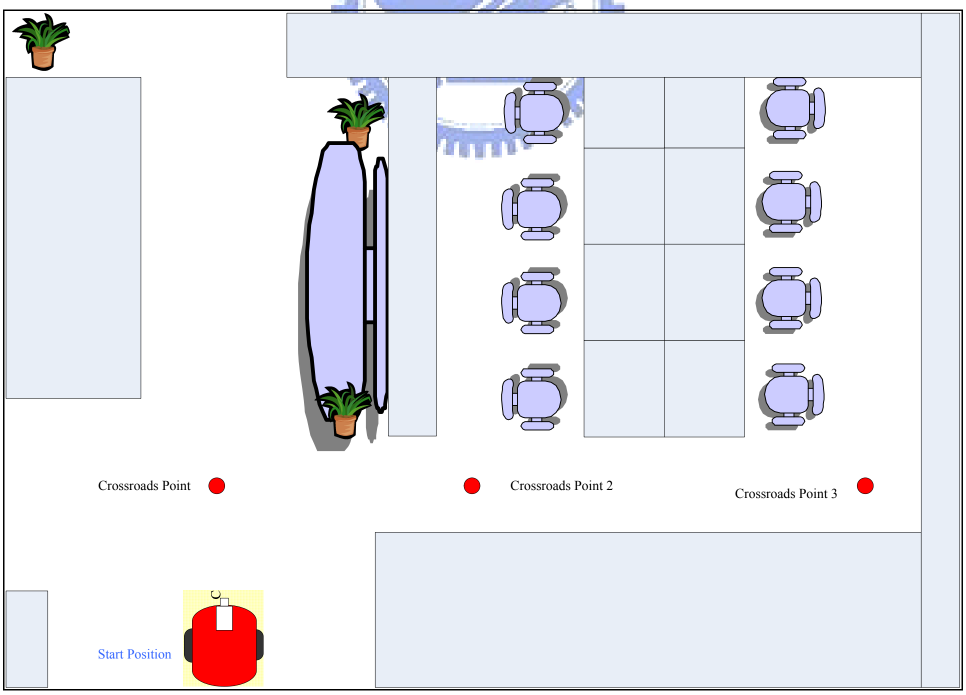

Figure 5.3 An illustration of the crossroads points.

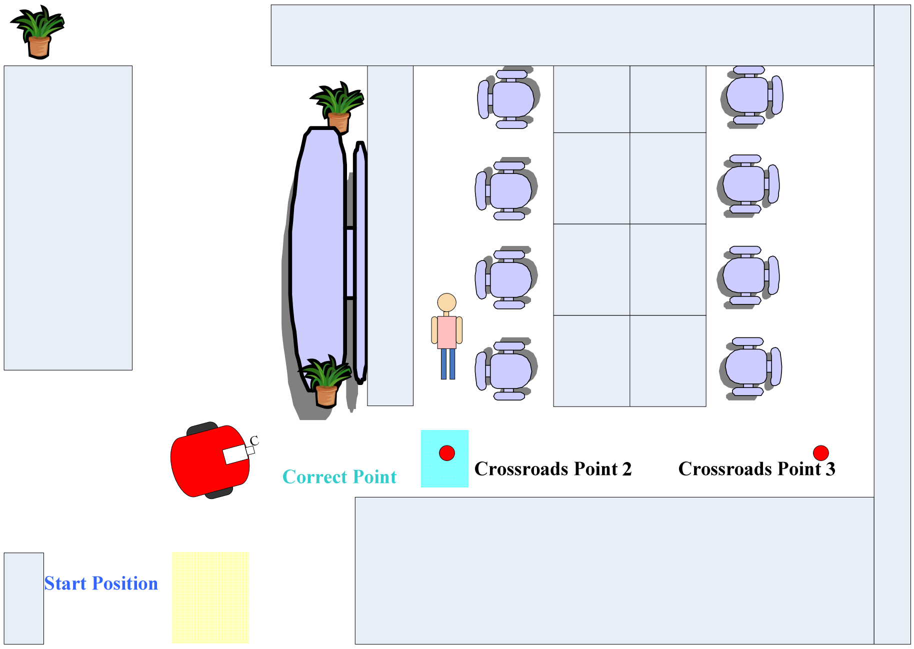

Figure 5.4 Choosing the correct crossroad point for searching the followed person.

5.3.2 Recording direction of fast human disappearance by a vehicle arm

Before we describe the method of turning to the direction of the disappearing person, we introduce the idea of using the robot arm equipped on the vehicle for human disappearance direction recording. First, we define the direction of the vehicle in the real world as illustrated by Figure 5.5 and assume that the vehicle faces the direction of 0° at the navigation starting position as shown in Figure 5.6.

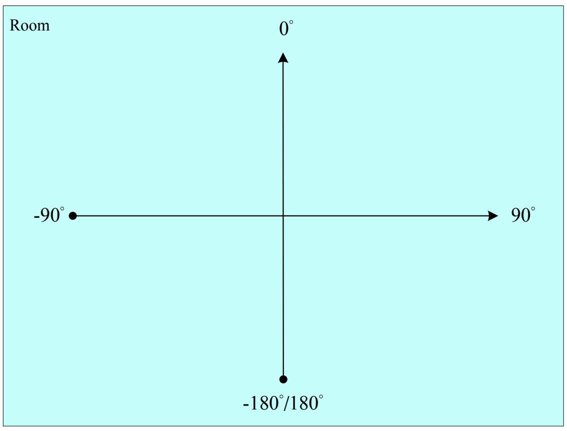

Figure 5.5 The direction of the vehicle in the real world.

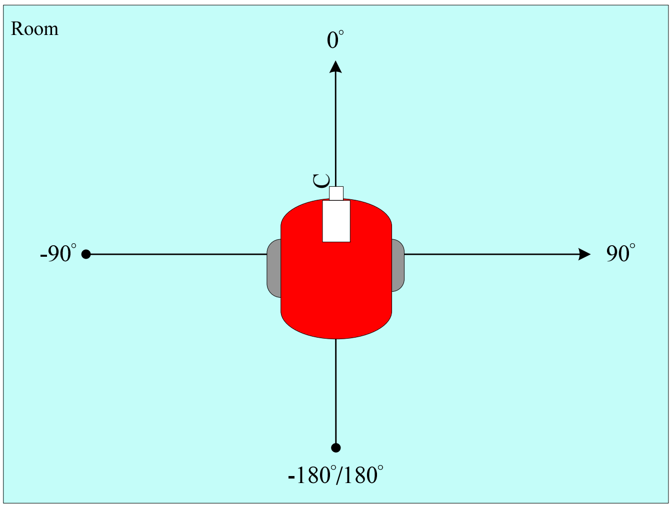

Figure 5.6 The original direction of the vehicle.

In Section 3.4.3, we have proposed a method for adjusting the orientation of the vehicle. However, if the person walks too fast, the vehicle cannot keep up with the person because the turning speed of the vehicle has a limit. Therefore, we use the robot arm which holds the camera to turn first and record the turning angle of the arm. By this method, when the person walks in a narrow path, the vehicle can be more sensitive to the changes of the person's position and adjust the orientation of the vehicle faster to prevent the vehicle from hitting the wall. The detail of the proposed method is described in the following as an algorithm. An illustration is shown in Figure 5.7.

Algorithm 5.3 *Recording the turning angle of the robot arm.*

Input: The center of the image $C_{image}(i_{cimage}, j_{cimage})$,the center of the clothes $C_a(i_{ca}, j_{ca})$ and threshold T_3.

Output: The turning angle θ of the arm.

Steps:

Step 1. Detect the center of the clothes $C_a(i_{ca}, j_{ca})$ by Algorithms 3.4 and 3.5.

Step 2. Compare the image center $C_{image}(i_{cimage}, j_{cimage})$ with the clothes center

$C_a(i_{ca}, j_{ca})$ by the following inequalities:

$$\left|i_{cimage} - i_{ca}\right| < T_3; \tag{5.4}$$

$$\left|j_{cimage} - j_{ca}\right| < T_3. \tag{5.5}$$

Where T_3 is a pre-selected threshold value. If Inequalities (5.4) and (5.5) are satisfied, we don't have to adjust the orientation of the camera because it means that the person does not move too much; else, go to Step 3

Step 3. Compute the longitude L_θ of $C_a(i_{ca}, j_{ca})$ by Algorithm3.6 and adjust the arm orientation for the value of L_θ. Set the desired value θ as the value L_θ.

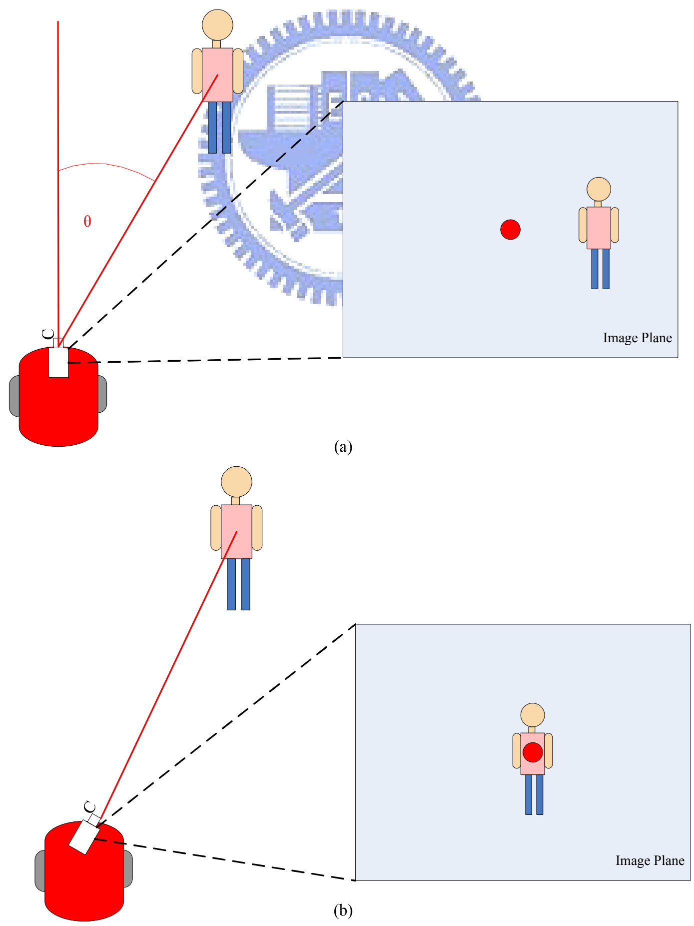

Figure 5.7 An illustration of turning the robotic arm. (a) The person is too right to the vehicle. (b) Adjust the degree of the arm.

Because the system records the turning angle of the arm all the time, when the person disappears, the vehicle can turn to the correct direction to search the person. When the person disappears, we use the turning angle of the arm to find out the side on which the disappearing person is, as shown in Figure 5.8. The detail of the proposed method is described in Algorithm 5.4 below.

Algorithm 5.4 *Turn to the direction of the disappearing person.*

Input: Current image I_c, the direction of the vehicle θ_v, the turning angle of the arm θ, and the turning direction *Direction*.

Output: Command the vehicle turn to the correct direction *Direction* with the angle θ_y for searching the disappearing person.

Steps:

Step 1. Detect the person in the current image I_c. If the person is considered to have disappeared, go to Step 2; else, go to Step 1.

Step 2. Decide the turning direction *Direction* in the following way;

$$\text{if } \theta > 0, \text{ then set } Direction = \text{'right;'} \tag{5.6}$$

$$\text{else, if } \theta < 0, \text{ then set } Direction = \text{'left.'} \tag{5.7}$$

Step 3. Compute θ_v' as the turning angle of the vehicle for the following cases, as shown in Figure 5.9.

Case 1: if the direction of the vehicle is between -45° and 45°, then set $\theta_v' = 0^\circ - \theta_v$.

Case 2: if the direction of the vehicle is between 45° and 135°, then set $\theta_v' = 90^\circ - \theta_v$.

Case 3: if the direction of the vehicle is between -45° and -135°, then set

$$\theta_v' = -90^\circ - \theta_v.$$

Case 4: if the direction of the vehicle is between 135° and 180°, then set

$$\theta_v' = 180^\circ - \theta_v.$$

Case 5: if the direction of the vehicle is between -180° and -135°, then set

$$\theta_v' = -180^\circ - \theta_v.$$

Step 4. If *Direction* is 'right,' then set $\theta_y = 90^\circ + \theta_v'$; else, set $\theta_y = 90^\circ - \theta_v'$.

Step 5. Command the vehicle turn to the correct direction *Direction* with the angle θ_y and search the followed person, as illustrated in Figure 5.10.

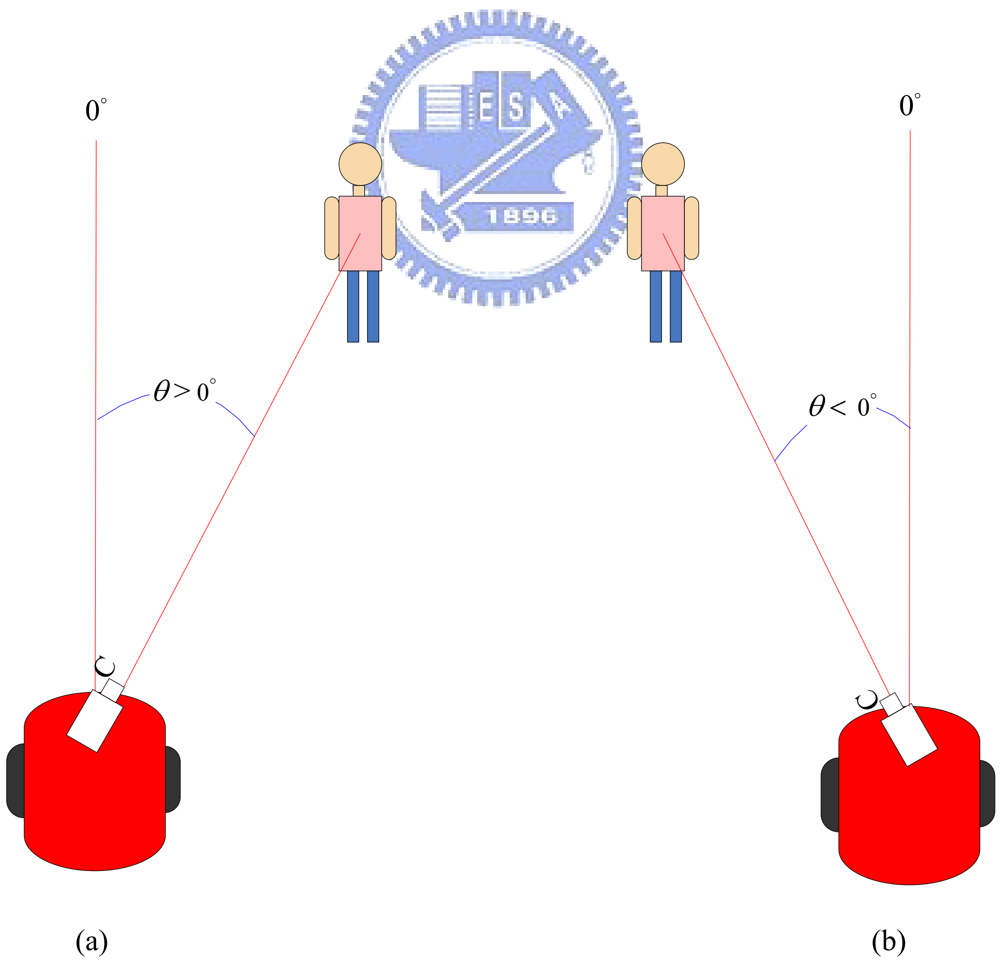

Figure 5.8 Measure the side of the turning direction. (a) Right. (b) Left.

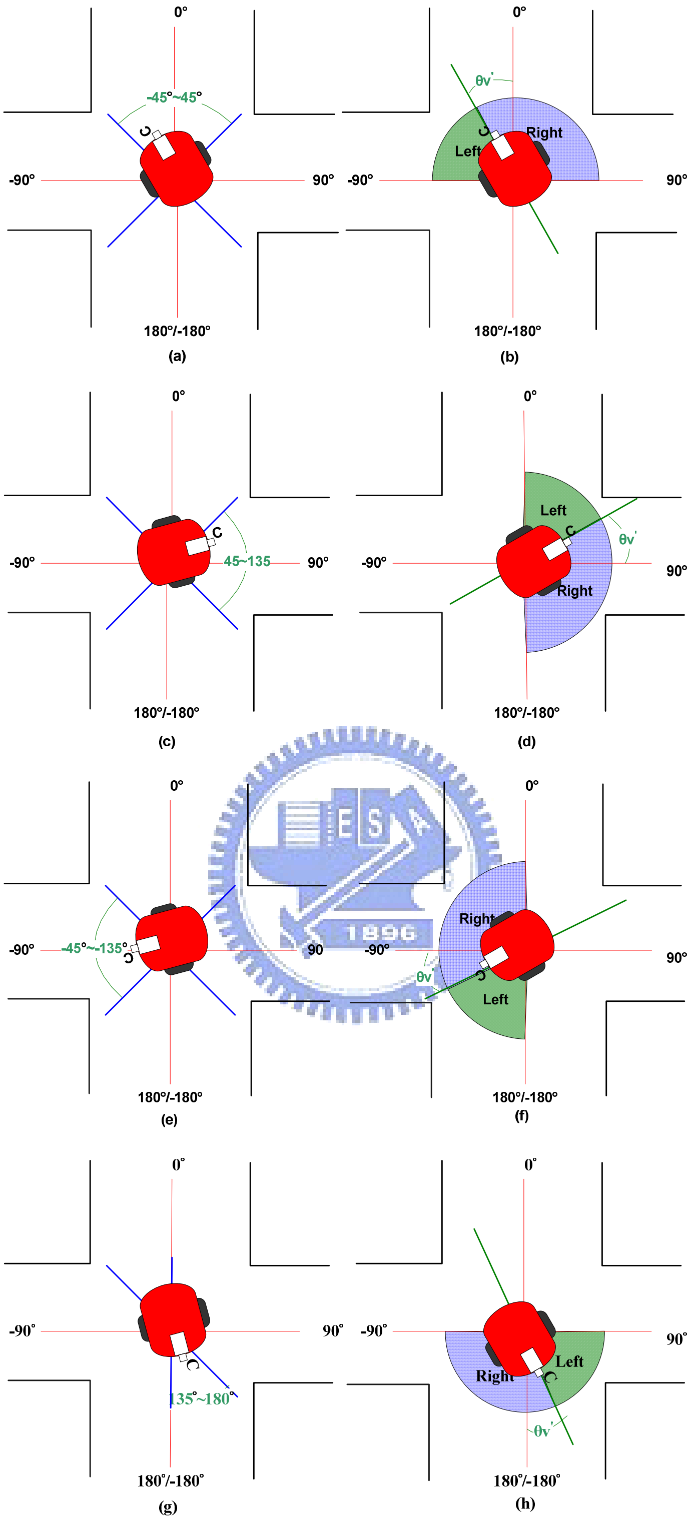

Figure 5.9 The direction of the vehicle (a) Case 1. (b) Right and left side of (a). (c) Case 2. (d) Right and left side of (c). (e) Case 3. (f) Right and left side of (e). (g) Case 4. (h) Right and left side of (g). (i) Case 5. (j) Right and left side of (j).

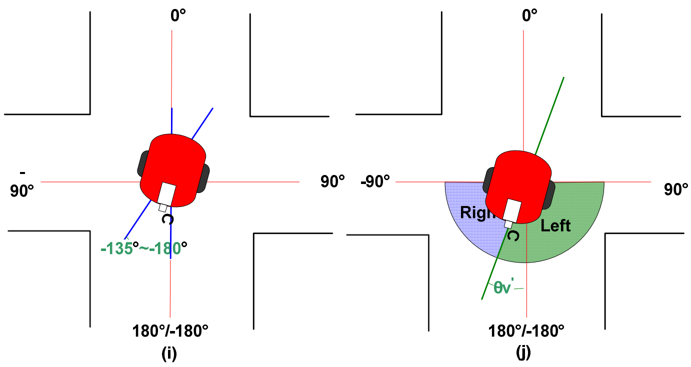

Figure 5.9 The direction of the vehicle (a) Case 1. (b) Right and left side of (a). (c) Case 2. (d) Right and left side of (c). (e) Case 3. (f) Right and left side of (e). (g) Case 4. (h) Right and left side of (g). (i) Case 5. (j) Right and left side of (j). (continued)

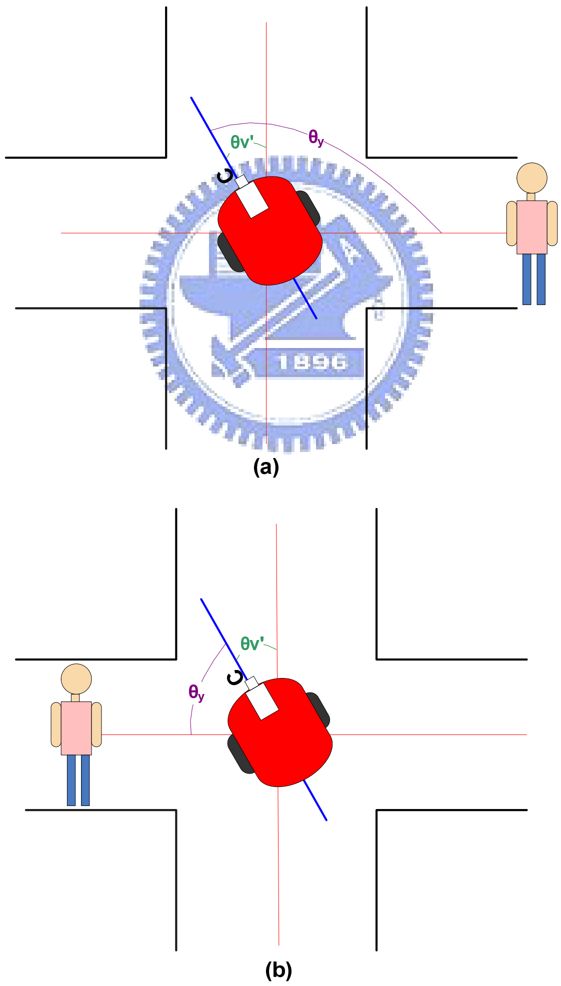

Figure 5.10 Turn to the correct direction (a) Turn right with angle θ_y. (b) Turn left with angle θ_y.