Parallel-Parking Control of Autonomous Mobile Robot

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Abstract **— This paper is devoted to design and implement a complete intelligent mechatronic system — a mobile robot possessing autonomous parallel parking capability. In this paper, the configuration of overall system is firstly introduced. The intelligent parallel-parking control method is addressed in the second topic, where a feasible reference path is provided for the fuzzy logic controller to maneuver the steering angle of the robot. The simulation results illustrate the effectiveness of the developed control algorithm. We not only investigate the intelligent parallel-parking control methods but also real-time maneuver the developed sensor-based mobile robot. The real-time control of the parallel parking system demonstrates the feasibility of the fuzzy control scheme.**

I. INTROUCTION

Design and implementation of the mechatronic system has become an appealing challenge for both academics and industries [1-5] worldwide. The autonomous mobile robot is one of the most commonly used mechatronics. This paper proposes a sensor-based navigation method and applies fuzzy logic theory to develop a real-time execution program such that the mobile robot performs the wayside parking autonomously. The fuzzy logic control (FLC) theory has been widely investigated over 30 years [6-9]. The knowledge base of a FLC can be obtained from human experts or from a referential data set. These concepts have been successfully applied in autonomous mobile robot control applications [10-20]. Parallel parking [21,24-27] is one of the most vital task in navigation [22] of autonomous mobile robot.

Many automotive applications, such as antilock braking systems (ABS), computer-controlled powertrain, and active suspension are applied to some cars. Other automotive applications of control technology such as parking control is currently being developed. It will be extensively used in the next-generation passenger cars for enhancing driver's safety and reducing the driving pressure.

II. SETUP OF THE MOBILE ROBOT

In order to simulate the parallel parking of a real car, we set up a 1/10th scale car-type robot and a micro-computer system is mounted on it. As [3] stated, the mechatronics can be defined as "the synergetic integration of mechanical engineering with electronic and intelligent computer control in the design and manufacturing of industrial products and processes." The setup of the mobile robot consists of the following four parts, robot mechanism, computer part, electronic driver, and sensor.

Fig. 1 shows the hardware architecture of the robot. The signal processing block diagram of a PC-based robot is shown in Fig. 2. There are six infrared sensors mounted on the mobile robot. The sensor arrangement of the robot is illustrated in Fig. 3. The microcomputer system arrangement is also presented. The appearance of the real autonomous mobile robot is shown in Figure 4. The setup of this mobile robot is addressed in detail in [27].

III. METHOLODOLOGY AND SIMULATIONS

The intention of this section is to find a reference path for parallel parking a nonholonomic autonomous vehicle. It is important for us to provide a reasonable reference path such that the autonomous mobile robot can successfully accomplish the parallel-parking mission. If the reference path is far from a feasible one because of the unmodelled dynamics or inaccuracy within the models, then the vehicle is unable to follow the path accurately. To avoid the abnormality, we must adopt a precise reference path for simulation application. Lyon [21] developed a smooth local reference path on the basis of the initial and final position, orientation and curvature.

There are several shaped curves used to be a reference path such as two circular arcs, sine curve, cosine curve, and a fifth-order polynomial curve [21,24,26]. All of them can adapt initial and final constraints. The disadvantage of these simple curves except the fifth-order polynomial curve is that they induce an extra time penalty in straightening out the wheel at the maneuver end-points.

The reference rear path during parallel parking is represented as a function $y_r = f(x_r)$. The general form of a fifth-order polynomial is given by

$$y_r(x_r) = a_5\left(\frac{x_r}{x_e}\right)^5 + a_4\left(\frac{x_r}{x_e}\right)^4 + a_3\left(\frac{x_r}{x_e}\right)^3 + a_2\left(\frac{x_r}{x_e}\right)^2 + a_1\left(\frac{x_r}{x_e}\right) + a_0 \tag{1}$$

and is conditional to constraints on slope

$$y_r' = \frac{dy_r}{dx_r}, \quad y_r'(0) = y_r'(x_e) = 0 \tag{2}$$

The curvature at the end points satisfies

$$k(0) = k(x_e) \tag{3}$$

and we have the reference path as below

$$y_r(x_r) = y_e\left[6\left(\frac{x_r}{x_e}\right)^5 - 15\left(\frac{x_r}{x_e}\right)^4 + 10\left(\frac{x_r}{x_e}\right)^3\right] \tag{4}$$

Fig. 5 depects the reference path solution — the tracks o the center of the rear and front of the vehicle. The geometri coordinate relation graph of a mobile robot is shown in Fig. 6 The vehicle body position is described in the coordinates X

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and Y, where all the corresponding parameters are defined as follows.

$F(x_f, y_f)$: position of the front wheel center of vehicle.

$R(x_r, y_r)$: position of the rear wheel center of vehicle.

ϕ : the orientation of the steering-wheels with respect to the frame of vehicle.

θ : the angle between vehicle frame orientation and X-axis.

l : the wheel-base of vehicle.

O : center of curvature.

r : distance from point O to point $F(x_f, y_f)$.

k : curvature of the fifth-order polynomial.

The motion of vehicle is described as

$$\dot{x}_r = v \cdot \cos\theta \cos\phi \tag{5a}$$

$$\dot{y}_r = v \cdot \sin\theta \cos\phi \tag{5b}$$

$$\dot{\theta} = v \cdot \frac{\sin\phi}{l} \tag{5c}$$

We propose a two-input-single-output fuzzy logic controller for the parallel-parking task. The vehicle used in the simulation has the following dimensions: length L = 4.45m, width W = 1.695m, and wheel base l = 2.62m. We define the angle between the orientation of line (x_{r1}, y_{r1}) (point on reference path) to (x_{r2}, y_{r2}) (position of the rear wheel center of vehicle) is θ_3 and the orientation of the reference path at (x_{r1}, y_{r1}) is θ_1. Then we have input $u1 = \theta_3 - \theta_1$. The second input $u2 = \theta_2 - \theta_1$ is defined as the angle between the orientation of the reference path at (x_{r1}, y_{r1}) and vehicle orientation θ_2.

Variable *u1* is decomposed into five fuzzy partitions. Variable *u2*, and control input ϕ are decomposed into seven fuzzy partitions. The partitions and the shapes of the membership functions are shown in Fig. 7, where the *u1* is divided into five regions, denoted by NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small), and PB (Positive Big), *u2* and ϕ are divided into seven regions, denoted by NB, NM (Negative Medium), NS, ZE, PS, PM (Positive Medium), and PB.

Control input ϕ presents the steering angle of front wheels. The rule table is designed as in Table 1. The degrees of all the values are these boxes equal the degrees of the "also" rule. The defuzzification strategy can be described as

$$\phi_{crisp} = \frac{\sum_{j=1}^{n} \mu_j(\phi_j) \cdot \phi_j}{\sum_{j=1}^{n} \mu_j(\phi_j)} \tag{6}$$

where ϕ_j is the mean value that supports of each fuzzy set j and n is the number of fuzzy sets, and $\mu_j(\phi_j)$ is the membership function value of the control input.

We exploit three cases [27] to test the proposed fuzzy backward parallel-parking control. One of them is shown as below. We simulate the movement of the vehicle from the initial state $(x_{r2}, y_{r2}, \theta_2) = (8, 3, 0°)$. The computer simulation trajectory is shown in Figure 8. The vehicle follows this reference path and parks in the lot rightly.

In addition, we apply the reference path method to the forward parallel parking. If the parallel parking lot is long enough to park the vehicle directly, we want to design a controller such that the vehicle moves forwards and directly parks in. The motion of vehicle is described as below.

$$\dot{x}_f = v \cdot \cos(\theta + \phi) \tag{7a}$$

$$\dot{y}_f = v \cdot \sin(\theta + \phi) \tag{7b}$$

$$\dot{\theta} = v \cdot \frac{\sin\phi}{l} \tag{7c}$$

We also adopt a two-input-single-output fuzzy controller for forward parallel-parking task. We defined the input $u1 = \theta_3 - \theta_1$ and the second input $u2 = \theta_2 - \theta_1$ just as we defined for backward parallel parking. For forward parallel parking, we test the feasibility of the fuzzy logic controller via following two cases [27]. We simulate the movement of the vehicle from the initial state $(x_{f2}, y_{f2}, \theta_2) = (-12, 5, 0°)$. The resulting trajectory is shown in Figure 9. The vehicle follows this reference path and parks forwards into the lot appropriately.

IV. IMPLEMENTIAL AND EXPERIMENTIAL RESULTS

A real-time control of the parallel parking system is presented in this section. Suppose there exist sensors such that x_f, y_f, and ϕ are measured as simulation before, then traditional control methods can easily get the parallel-parking job down with following a reference path. In general, it is difficult to detect the absolute coordinate values of x_f, y_f, and ϕ. In this paper, we exploit six UF55MG sensors to measure the relative distance and orientation between the robot and parking lot. The control commands of the robot are the velocity of the robot v and the orientation of the steering wheels with respect to the frame of the robot θ.

Variables *u1, u2,* and control input ϕ are decomposed into seven fuzzy partitions. The partitions and the shape of the membership functions are shown in Fig. 10. The intelligent computer control used in this study is in fact the PC-based fuzzy logic control. That is, we want to design a FLC for the robot such that the mobile robot can accomplish the parallel-parking problem appropriately and automatically. To evaluate the feasibility and effectiveness of a FLC, we set up two cases of parallel parking. These two cases are shown in Fig. 11.

In backward parallel parking, the parking lot is not enough long to park the mobile robot directly. It must pass the parking area first and back the mobile robot into the parking area.

In forward parallel parking, the parking lot is long enough to park the mobile robot. Thus, mobile robot move forwards and directly parks in as sensors detect the parking area.

A. Backward Parallel Parking

For realizing parallel parking control of the autonomous mobile robot, we consider a robot moving backwards into a parking lot in a course as in Fig. 12, where d0 presents the distance measured by the infrared sensor (s0) from the center of the rear body to the wall; d1 is the distance measured by the infrared sensor (s1) from the rear wheel of the robot to the wall; d2 devotes the distance measured by the infrared sensor (s2) from the steering wheel of the robot to the wall; and d5 represents the distance measured by the infrared sensor (s5) from the center of the front body to the wall.

For deriving the fuzzy control rules, we district the process of parking a robot to four sorts of situations.

Situation 1: Mobile robot detects the parking lot and passes it with the original orientation. In this case, it is important for the robot to maintain a constant distance with respect to the wall.

Situation 2: Robot moves reversely along the parking lot wall until the whole or most part of the robot enters the parking lot and stops at the other side of parking lot.

Situation 3: Examine the position of robot whether it is properly staying in the parking lot via sensors. If the position of robot does not meet the required meats, robot moves forwards in parking lot to correct its parking position.

Situation 4: Examine the position of robot whether it is properly staying in the parking lot via sensors. If the position of robot does not meet our goal, robot moves backwards in parking lot to correct its parking position.

The movements of Situation 3 and Situation 4 are repeated until the robot reaches the desired destination. The desired destination is both d0-d5 and d1-d2 are almost zero. Fig. 13 shows the four control situations for backward parallel parking.

B. Forward Parallel Parking

When the parallel parking lot is long enough to park the mobile robot, mobile robot moves forwards and directly parks in as sensors detect the parking lot. For realizing parallel parking control of the autonomous mobile robot, we consider a robot moving forward into a parking lot in a course as illustrated in Fig. 14. We decompose the process of parking a robot into three sorts of situations which are addressed in [27].

All the real-time maneuver processes are taken by photograph and recorded in videotape. The practical experiment photographs for backward parallel parking are shown in Fig. 15.

V. CONCLUSION

In this paper, we have designed and implemented an intelligent mechatronics — an autonomous mobile robot. An intelligent controller for the parallel parking system has been developed on the basis of the fuzzy logic control scheme. All the simulation and experimental results illustrate the effectiveness of the controller algorithm.

VI. ACKNOWLEDGMENT

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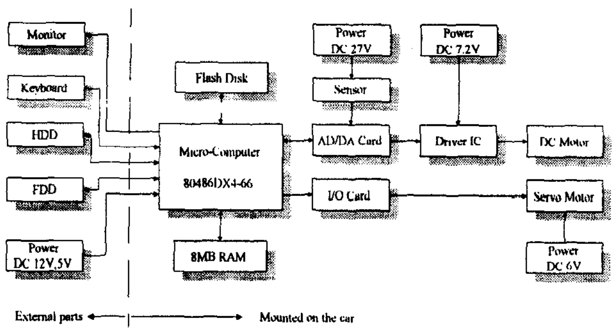


Fig.1 Hardware architecture of the mobile robot.

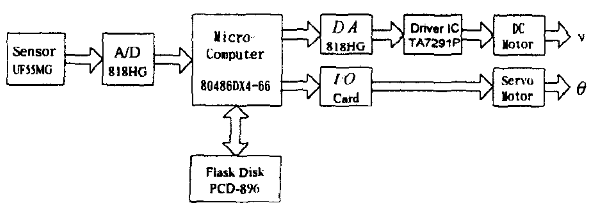


Fig. 2 The signal processing block diagram of the mobile robot.

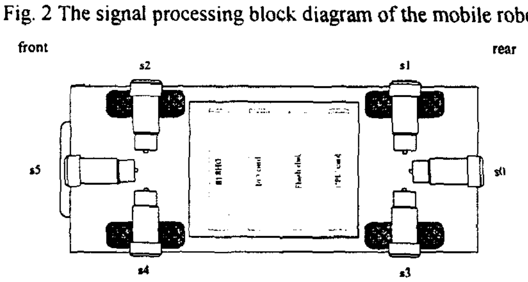


Figure 3. Sensor arrangement.

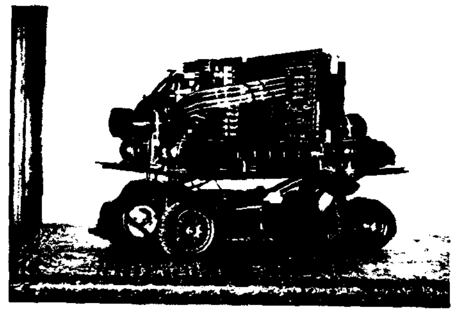


Fig. 4 The appearance of the mobile robot.

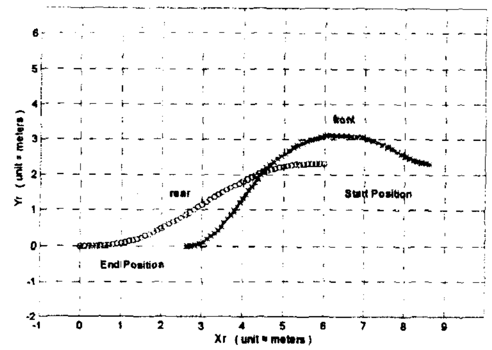


Fig. 5 The reference path with start position $(x_e, y_e) = (6, 2.3)$ and end position $(x_e, y_e) = (0, 0)$.

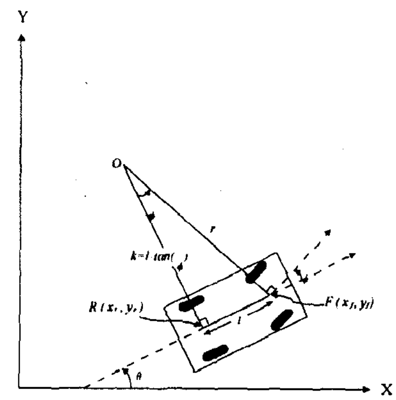
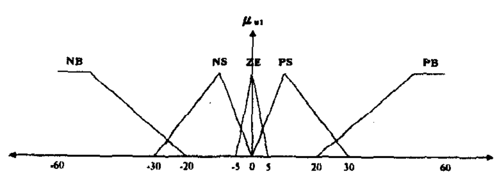
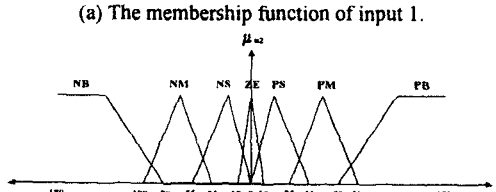


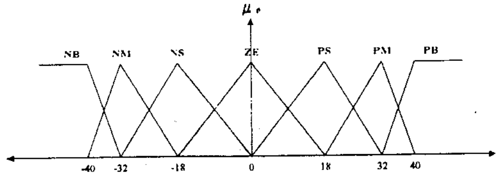
Fig. 6 Car-type vehicle.



(a) The membership function of input 1.



(b) The membership function of input 2.



(c) The membership function of control input ϕ.

Fig. 7 Fuzzy membership functions in simulation case.

Table 1 The fuzzy rule table for backward parallel parking.

u2 \ u1 ϕ	NB	NS	ZE	PS	PB
NB	NM	NB	NB	NB	NB
NM	NS	NM	NB	NB	NB
NS	PM	NS	NM	NB	NB
ZE	PM	PM	ZE	NM	NM
PS	PB	PB	PM	PS	NM
PM	PB	PB	PB	PM	PS
PB	PB	PB	PB	PB	PM

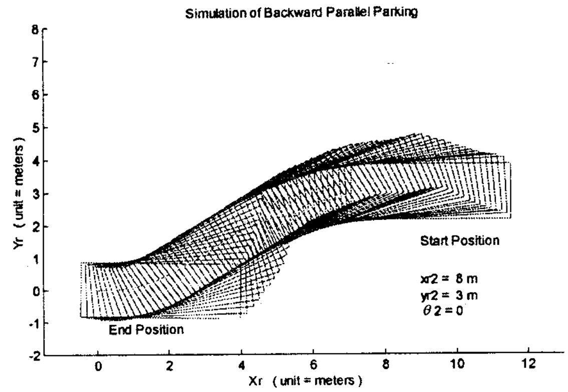


Fig. 8 Simulation result of backward parallel parking.

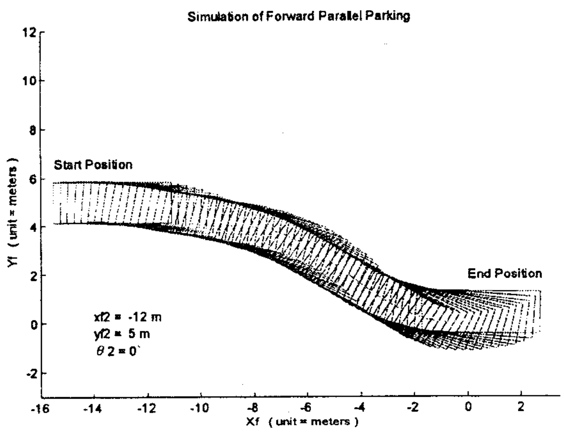
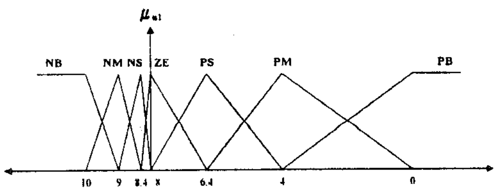
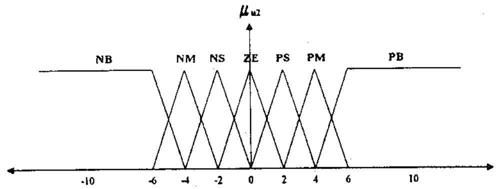


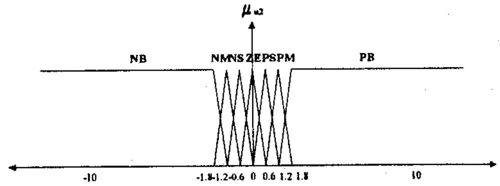
Fig. 9 Simulation result of forward parallel parking.



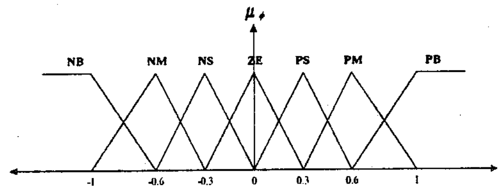
(a) The membership function of input 1.



(b) The membership function of input 2.

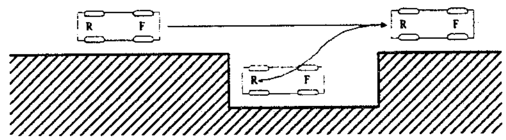


(c) The membership function of input 2 when d1 is less than the constant distance from robot to wall.

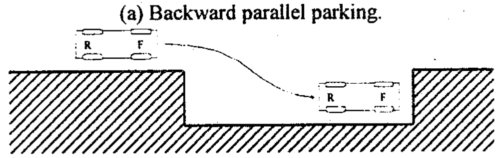


(d) The membership function of control input ϕ.

Fig. 10 Fuzzy membership functions for the robot parallel parking control.



(a) Backward parallel parking.



(b) Forward parallel parking.

Fig. 11 Two cases of parallel parking.

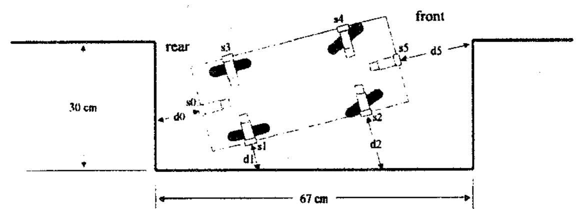
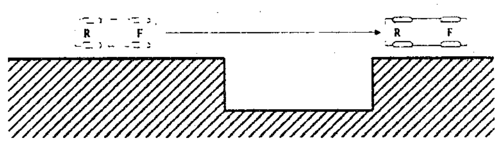
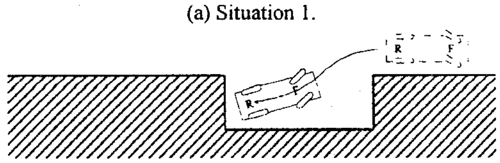


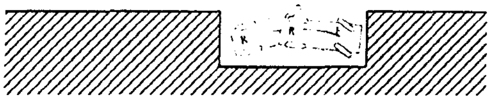
Fig. 12 Definition of the input variables for backward parallel parking.



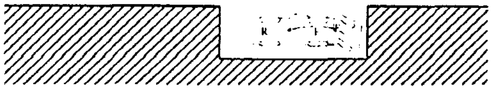
(a) Situation 1.



(b) Situation 2.



(c) Situation 3.



(d) Situation 4.

Fig. 13 Four situations for backward parallel parking.

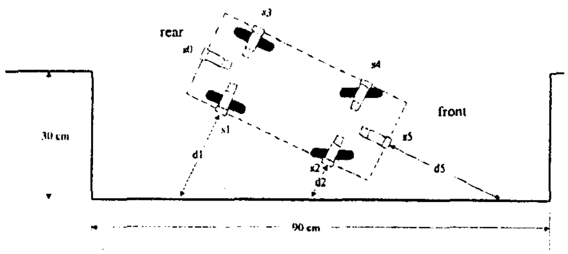


Fig. 14 Definition of the input variables for forward parallel parking.

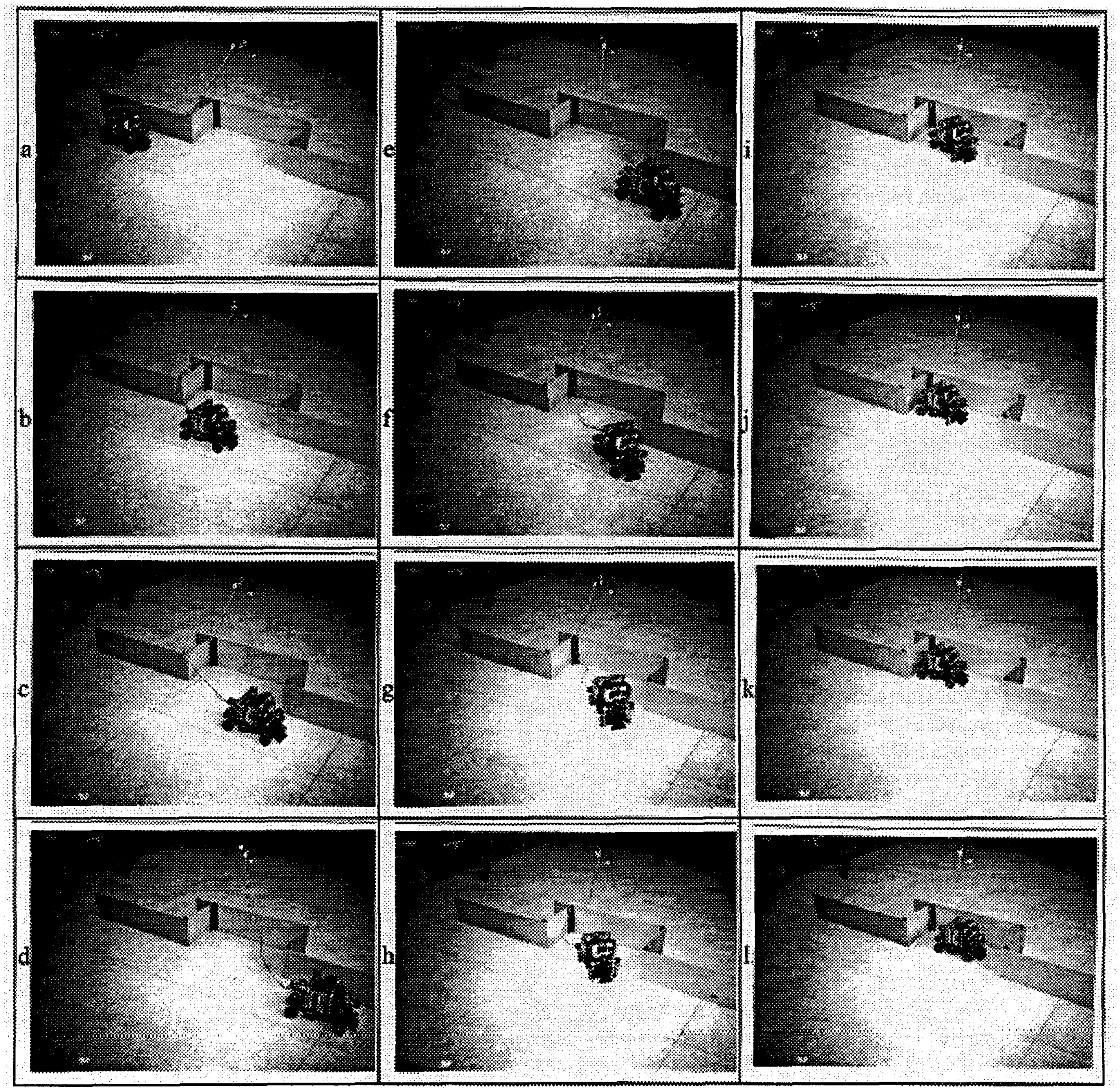


Figure 15. The real-time implementation of intelligent parallel parking control.