

Autonomous Parallel Parking of a Car Based on Parking Space Detection and Fuzzy Controller

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Abstract

This paper develops an automatic parking algorithm based on a fuzzy logic controller with the vehicle pose for the input and the steering angle for the output. In this way some feasible reference trajectory path have been introduced according to geometric and kinematic constraints and nonholonomic constraints to simulate motion path of car. Also a novel method is used for parking space detection according to image processing. A fuzzy controller according to experiments of skilled driver and path planning is designed, and then fuzzy rules are tuned and finally fuzzy membership functions are optimized using genetic algorithm. Simulation results illustrate the effectiveness of the developed schemes.

Keywords: Automatic car parking – Fuzzy controller – Image processing – Optimization-Smart cars

1. INTRODUCTION

Intensive research is carried out in the automotive industry for the development of intelligent automobiles that can make the driving procedure easier and more secure.

An automatic parking system (APS) can park the vehicle for inexperienced drivers. Though some automobile companies have recently developed parking assistance systems (PAS) or APS, issues on safety and cost still remains for commercialization.

The research in car parking problem is derived from the general motion planning problem and is usually defined as finding a path that connects the initial configuration to the final one with collision-free capabilities and by considering the nonholonomic constraints[1].

The path planner of a car has to meet holonomic constraints which mean: (1) the movement direction must always be tangent to its trajectory and (2) the turning radius is mechanically limited to a minimum value, which is equivalent to saying that vehicle curvature is upper bounded[2].

For offline path planning in the absence of obstacles, the parking problem can be defined as finding the shortest paths connecting two given initial and final configurations [3,4]. It has been shown by Dubins [3] that the shortest path for a car-like vehicle is arcs of circle (with minimum turning radius) connected with straight line segments. But the

problem about this path is that the curvature profile is discontinuous between arcs and straight lines, so that the robot has to stop at each discontinuity point at line–arc transition to reorient the front wheels. Since instantaneous changes in steering mechanisms are physically impossible, it results in errors of the state of the vehicle at these transition points.

Among path tracking approaches, Jiang et al. [5] studied sensor guided autonomous parallel parking, where the process consists of scanning, positioning and two maneuvering. The path in the maneuvering phase is composed of two circular arcs of minimum radius tangentially linked to each other, and to avoid collision a forbidden area inside the parking slot is defined. They used the ultrasonic sensors for parking. Ultrasonic sensors normally have the distance error to the angle of reflection as well as can not obtain the distance in a parking lot without obstacles.

Daxwanger [6] bypassed pose estimation by using a neural network that can directly map the video sensor's image of the environment to a corresponding steering angle. However, this approach may not generalize well in untrained environments.

In order to improve the parking performance, Zhao [7] optimized the fuzzy membership functions using a genetic algorithm (GA) based on heuristic rules. However, they did not consider parking performance factors such as the collision possibility and the overall parking time. Furthermore, all this research used the odometry data obtained from the wheel encoders,

which is not really practical. We think that image and sonar based localization will be a more practical choice for automatic parking. Further, the automatic parking algorithm must consider parking accuracy in real experiments.

In this paper a method for detecting parking space dimension based on vision sensors has been presented. Vision is chosen as the main perception system because of rich information in images and the immunity to interference and noise. By image processing and vision computing, we can detect an empty parking slot from the images.

Once the detection of free parking slot has been completed, the next step is to plan a proper path that will bring the vehicle into the empty slot. The solution is based on the analysis of parking strategy and local path planning. Fifth-order polynomial reference paths for many different ready to reverse point have been used to generate the data for designing rules for controller.

This paper is organized as follows. In Section 2, kinematic equations and constraints are described and based on them the reference path for parallel parking is derived and then in Section 3 parking slot is detected using image processing. In section 4, a fuzzy controller is designed based on optimized path that is obtained in section 2 and experience of skilled driver. And finally in section 5, for minimization final parking error fuzzy controller is optimized using genetic algorithm.

2. KINEMATIC EQUATIONS AND REFERENCE TRAJECTORIES

Consider a kinematic model of a car shown in Fig. 2, where the rear wheels are fixed parallel to car body and allowed to roll or spin but without slip. The front wheels can turn to left or right, but the left and right front wheels must be parallel. All the corresponding parameters of the vehicle depicted in Fig. 2 are defined as follows:

- (x_f, y_f) : position of the front wheel center of car;
- (x_r, y_r) : position of the rear wheel center of car;
- ϕ : orientation of the steering-wheels with respect to the frame of car;
- θ : angle between vehicle frame orientation and X-axis;
- l : wheel-base of car;

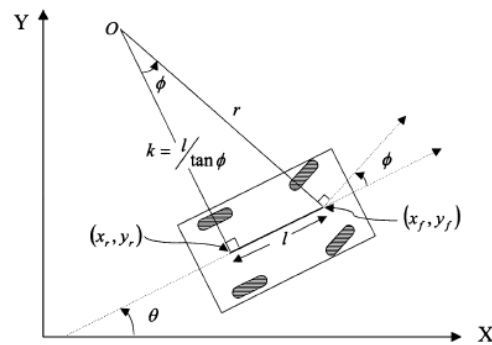


Fig. 1. Kinematic model of a car

- O : center of curvature;
- r : distance from point to point ;
- k : curvature of the fifth-order polynomial.

The general expression for curvature of any curve is $k = \frac{d\theta}{ds}$, where s is the path-length variable and θ is the angle of the tangent to the path. For a path defined in Cartesian coordinates, curvature of $y(x)$ is given by:

$$k = \frac{\frac{d^2y}{dx^2}}{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{\frac{3}{2}}} \quad (1)$$

Since the vehicle velocity during the maneuver is very small, we have used only kinematic equations for system modeling. The simple kinematic model usually used for the vehicle is [8]:

$$\begin{aligned} \dot{x}_r &= v \cdot \cos\theta \cos\phi \\ \dot{y}_r &= v \cdot \sin\theta \cos\phi \\ \dot{\theta} &= v \cdot \frac{\sin\phi}{l} \end{aligned} \quad (2)$$

Among polynomial curves it has been shown that a fifth-order polynomial is the least polynomial behaving the parallel parking [2,9,10]. The curvature of this path (shown in Fig.3) confirms that the desired continuous-curvature path is provided and also the vehicle will be able to straighten out its wheels at the maneuver end points. In this figure, (x_s, y_s) and (x_g, y_g) , respectively, represent start and target points. As can be seen, the maximum curvature increases directly with the ratio (y_s/x_s) . This ratio must be chosen sufficiently low, so that the resulting continuous steering function dose not violate the peak turning angle and hence the second nonholonomic constraint [2]. Constraints on this curve include initial and final positions, orientation and curvature as well as the non-holonomic constraints.

The path of the mid-point of the rear axle is represented as a function $y = f(x)$. The general form of a fifth-order polynomial is given by [2]:

$$y(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 \quad (3)$$

That is subjected to zero slope and curvature at the start and target configuration.

$$\begin{aligned} y(x_s) &= y_s & y(x_g) &= y_g \\ \dot{y}(x_s) &= 0 & \dot{y}(x_g) &= 0 \\ \ddot{y}(x_s) &= 0 & \ddot{y}(x_g) &= 0 \end{aligned} \quad (4)$$

The six coefficients in equation (3) can be found to satisfy the position, slope and curvature constraints of this maneuver.

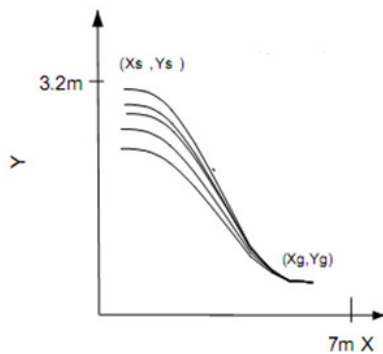


Fig. 2. Fifth order polynomial curves for different initial positions[2]

Therefore according to the equation (2) and also slope of polynomial equation we have:

$$\varphi = \sin^{-1} \left(\frac{1}{r} \right) \quad (5)$$

According to equation (5) we can calculate proper steering angle appropriate with position of middle point of rear axle.

3. RECOGNITION OF PARKING SPACE FROM PICTURE

Image Processing is one of quick and accurate methods for recognition of Park Place, that nowadays is used widely for recognition in Intelligent Automobiles. In this part will be explained the steps of

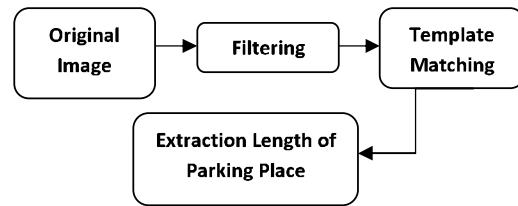


Fig. 3. Image processing algorithm

image processing on park place picture for Recognition of park Length. Fig (3) illustrates summarization of processing algorithm for estimation of parking place length.

3. 1. Filtering:

For computation of Park Length, at first should be do preprocessing for providing the obtained picture from automobile camera. These preprocessing include some filters.

3. 1. 1. Converting indexed image to grayscale image

In initial step color image is changed to gray image for simply computation (fig.4). One pixel will be have gray value if red, blue and green coefficients relate to this pixel are equal.

If original image is RGB image, is used following formula to grayscale:

$$S_R(x, y) = S_G(x, y) = S_B(x, y) = [R(x, y) + G(x, y) + B(x, y)] / 3$$

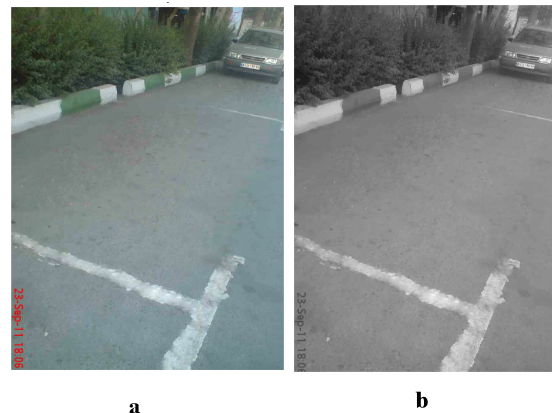


Fig. 4. (a) Original Image. (b) Gray Image

3. 1. 2. Calculating of the Image Histogram

Image histogram is a graph that defines the number of pixels per brightness levels in the input image. In fact histogram is graphic expression of brightness levels. The histogram of digital image with gray levels in the range $[0, L-1]$ is a discrete function $h(r_k)=n_k$, where r_k is the k th gray level and n_k is the number of pixel in the image having gray level r_k . It is common practice to normalize a histogram by dividing each of its value by the total number of pixels in the image, denoted by n .

Histogram is used to increase the low contrast of images. An image with low contrast has a histogram that will be narrow and be centered toward the middle of the gray scale. Histogram equalization increases the contrast of input image, so that the output gray levels will be in the same range.

Result of the Histogram equalization is shown in Figure (5).



Fig. 5. Result of the Histogram equalization.

3. 1. 3. Use of Second Derivatives - LapLacian

Because the Laplacian is a derivative operator, its use highlights gray-level discontinuities in an image and deemphasizes regions with slowly varying gray levels. This will tend to produce images that have grayish edge lines and other discontinuities, all superimposed on a dark, featureless background.

It can be shown that simplest isotropic derivative operator is the Laplacian, which, for an image $f(x,y)$ of two variable [11], is defined as:

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \quad (6)$$

The digital implementation of the two dimensions

Laplacian is obtained by summing these two components [11]:

$$\nabla^2 f(x,y) = f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1) - f(x,y) \quad (7)$$

This equation can be implemented using the following filter:

$$w = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

That gives an isotropic result for rotations in increments of 90 °C. Figure (6-a) shows the result of applying Laplacian filter and Figure (6-b) shows the binary image of (6-a). It can be seen in Fig (6-b) the image has a lot of noise.

We used a spatial filter of the type of motion, that give the approximation of linear motion of camera, to eliminate noise. Figure 7 shows the image after the filter.

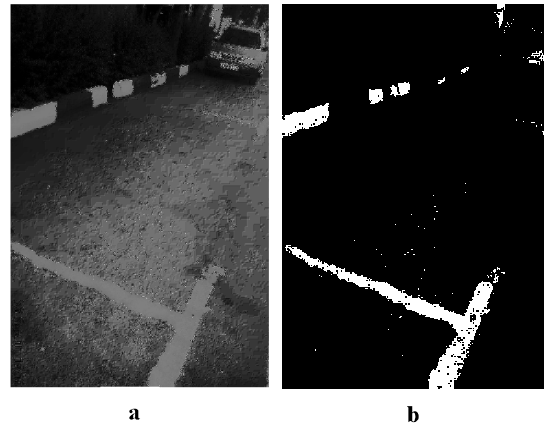


Fig. 6. (a) shows the result of applying Laplacian filter. (b) Binary image of it

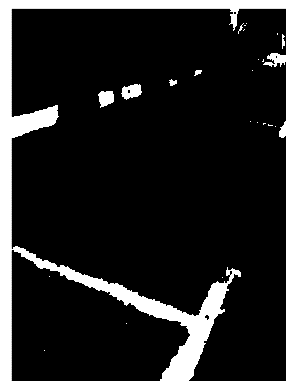


Fig. 7. The image after the motion filter

3. 2. Template Matching By Correlation

Correlation is quite simple in principle. Given an image $f(x,y)$ the correlation problem is to find all places in the match a given subimage (also called a mask or template) $\omega(x,y)$. Typically, $\omega(x,y)$ is much smaller than $f(x,y)$. For prototyping, an alternative approach is to implement correlation in the frequency domain [11].

$$\gamma(x,y) = \frac{\sum_{s,t} [\omega(s,t) - \bar{\omega}] [f(x+s, y+t) - \bar{f}_{xy}]}{\sqrt{\sum_{s,t} [\omega(s,t) - \bar{\omega}]^2 \sum_{s,t} [f(x+s, y+t) - \bar{f}_{xy}]^2}} \quad (8)$$

Where ω is a template, $\bar{\omega}$ is the average value of template pixels, f is image and $\bar{f}_{xy}$ is the average value of image where that image and template overlap. Denominator will be normalized the obtained results than intensity changes. Values of $\gamma(x,y)$ are in the range $[-1, 1]$, if $|\gamma(x,y)|$ be more, matching between image and template is more.

The goal in the automobile park problem is to find park place length from image. For computing parking place length by signage of park place. First we



Fig. 8. Mask's image



Fig. 9. Detecting of parking space's length

obtained Correlation between final image (fig. 7) and template image (mask). Mask image is shown in figure 8. The result of this Correlation is clear location of the image that be more consistent with mask. So locations of park place lines are determined. Then Euclidean distance between the centers of the marks is calculated to obtained parking space length according to camera features (Fig. 9).

4. DESIGN OF FUZZY CONTROLLER

Fuzzy systems employ a mode of approximate reasoning which enables them to make robust and meaningful decisions under uncertainty and partial knowledge. The nature of fuzzy logic leads to robust control algorithms in spite of sensor uncertainties and control errors.

In addition, fuzzy logic control provides the flexibility to apply a non-linear control law derived from an experienced human-driver and expressed using words and If-Then rules. Further, fuzzy logic navigation allows various behaviors to be easily combined through a command fusion process.

In this paper for car navigation to parking slot, fuzzy controller has been used. Therefore for locating vehicle in appropriate parking position, the proper steering angle according to the position of the vehicle in every moment should be constructed. Here to obtain proper steering angle in each position, two sources has been applied. The first source is using of simulated path curvature and the second source is based on skilled driver experiences.

Assume that a rule is produced based on input-output pairs (x_0^p, y_0^p) . Then it's confidence degree is defined like [12]:

$$D(\text{rule}) = \prod_{i=1}^n \mu_{A^i} (x^p_{oi}) \mu_{B^i} (y^p_{oi}) \quad (9)$$

Where :

$\mu_{A^i} (x^p_{oi})$: is membership function's value of ith input

$\mu_{B^i} (y^p_{oi})$: is membership function's value of ith output

Which with determination of confidence's degree, controller's rules are defined (table 1).

Table 1. Fuzzy rule sets

$\begin{matrix} x \\ \text{teta} \end{matrix}$	VS	S	M	L	VL
N	*	PS	NS	*	*
M	P	PB	N	N	N
PS	PS	PB	NB	NB	N
PM	*	PB	NB	NB	PS
PL	*	P	P	NB	*

4. 1. Determination of Inputs and output variables

At the first inputs and output variables are determined. Vehicle position is as input which is represented with vehicle position in x-direction and vehicle's angle respect to the horizontal line. Origin of the coordinate system is located at the rear right corner of parking lot. and steering angle ϕ is output of the controller. The variables range is:

$$0 < x \leq 8$$

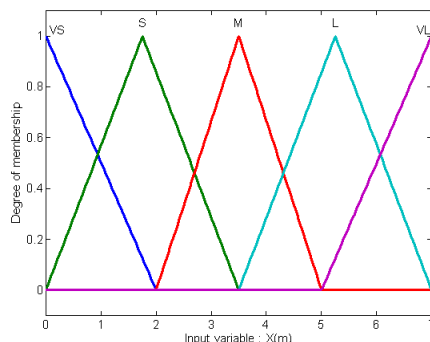
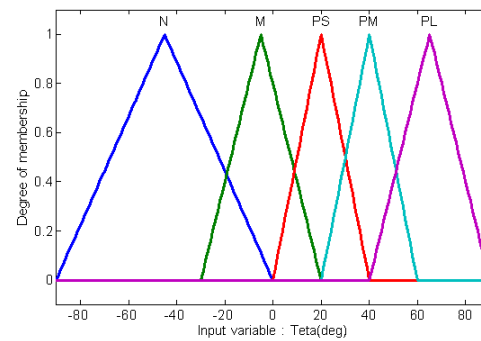
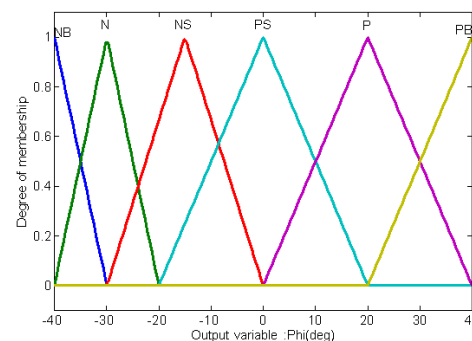
$$-90 < \theta < 90$$

$$-40 < \phi < 40$$

Positive values of ϕ shows clock wise rotation of wheels, and negative values of ϕ shows counter-clock wise rotation of wheels.

4. 2. Fuzzy Sets

In the next step the values of input-output fuzzy sets are defined. Fuzzy sets represent verbal semesters. We chose the following membership functions for these fuzzy sets:

**Fig. 10.** MF(x)**Fig. 11.** MF(θ)**Fig. 12.** MF(φ)

Based on this fuzzy partitioning, the qualitative description looks like:

In the case of $[x, \theta, \phi] = [S, N, PS]$ if the vehicle is near the final parking position and it's orientation is small it should maintain the current orientation for driving toward the parking space.

In the case of $[x, \theta, \phi] = [VL, M, N]$ if the vehicle is near the maneuver starting position and it's orientation is small the vehicle should turn in a small angle counterclockwise to track desired path for parking.

5. Optimization of Fuzzy Membership Functions With Genetic Algorithm

If the number of x , θ , ϕ membership functions are m_1 , m_2 and m_3 respectively then the p th individual of fuzzy model is defined:

$$s_p(t) = [v_1^{e_x} v_2^{e_x} \dots v_{m_1}^{e_x} v_1^{e_\theta} v_2^{e_\theta} \dots v_{m_2}^{e_\theta} v_1^{e_\phi} v_2^{e_\phi} \dots v_{m_3}^{e_\phi}] \quad (10)$$

Where $V_{i^c x}$ ($i=1, 2, \dots, m_1$) and $V_{i^c \theta}$ ($i=1, 2, \dots, m_2$) and $V_{i^c \phi}$ ($i=1, 2, \dots, m_3$) are i th and j th input and k th output membership functions variable respectively.

Hence the most important objective is to minimize vehicle parking position error. We define objective function as:

$$error_{cost_{fun}} = \sqrt{w_1 e_x^2 + w_2 e_y^2 + w_3 e_\theta^2} \quad (11)$$

Where w_1, w_2, w_3 are weighting coefficient and e_x, e_y, e_θ are controller variable errors.

According to the minimizing of position error, the modified membership functions are obtained as shown in figure 13.

in figure 14.

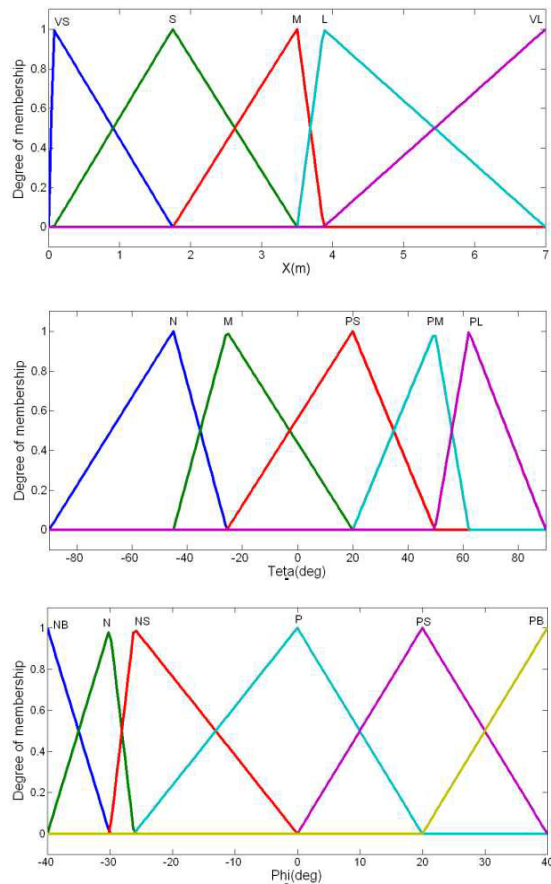


Fig. 13. Modified MF's

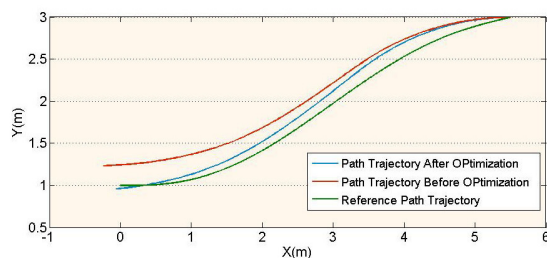
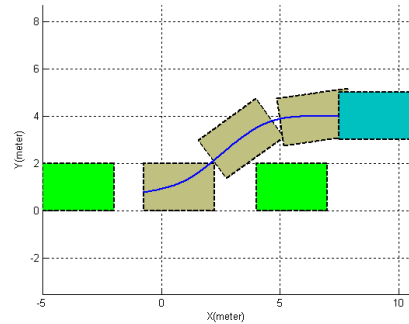
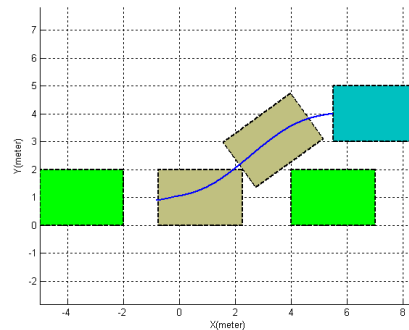


Fig. 14. optimized trajectory path

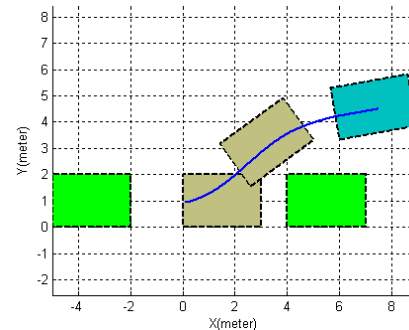
Figure (14) shows the effectiveness of optimization. And shows final parking error is less than 5 cm.



a: $x=7.5m$ $y=4m$ $\theta=0$



b: $x=5.5m$ $y=4m$ $\theta=0$



c: $x=7.5m$ $y=4m$ $\theta=10deg$

Fig. 15. Path trajectory of vehicle during maneuver under various initial position

Figure (15) shows vehicle's path trajectory under various initial position.

Initial position of vehicle at the start of maneuver or ready to reverse point is an important factor in accuracy of vehicle final position. If the initial position was out of allowable range, controller couldn't park vehicle properly. As can see from these figures if initial x-position range was [5.5-7] and y-

position range was [5.5-7.5], vehicle could be parked properly. Also initial angle is important factor in having proper maneuver with no collision. We assume that vehicle initial position is parallel to parking lot, but the controller navigate vehicle properly up to 10 degree initial angle (Fig 15-c).

6. CONCLUSIONS

In this paper a novel automated parking utilizing image processing, an automated fuzzy controller design, based on using of simulated path curvature and skilled driver experiences has been presented. The contributions are:

Efficient parking space detecting: we proposed an algorithm for detecting parking lot through parking markers and it can detect proper parking lot even the markers are damaged with measuring it's size.

Fuzzy controller could properly control vehicle from initial position to final position.

When vehicle is not parallel to parking lot, controller could control vehicle till 10 degree offset.

Initial position of car or on the other hand ready to reverse point is an important factor in accuracy of final parking position. It has been shown that proposed controller with rule tuned could perform well with 2m deviation in x-direction.

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