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Procedia Computer Science 133 (2018) 82–91

Procedia Computer Science

www.elsevier.com/locate/procedia

International Conference on Robotics and Smart Manufacturing (RoSMa2018)

An Intelligent Fuzzy based Hybrid Approach for Parallel Parking in Dynamic Environment

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Abstract

Intelligent vehicle parking problem is considered as a challenging problem due to requirement of human-like expertise. In literature, it is generally considered as a standalone problem where parking feasibilities are inherently assumed and solutions are discussed. This paper proposes a novel hybrid fuzzy-based approach for parallel parking where intelligent system considers multiple parking scenarios in which parking problem is considered as an extension of navigation problem. It incorporates mimicking human-like intelligence in dynamic environmental conditions while, parking in the given slots either slot becomes pre occupied due to arrival of another vehicle or sudden appearance of obstacles during parking is in progress. Simulation results show the effectiveness of proposed solution for different maneuvering scenarios.

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Peer-review under responsibility of the scientific committee of the International Conference on Robotics and Smart Manufacturing.

Keywords: Multiple Parking; CLMR; Parallel Parking; Forward and Reverse parking; Fuzzy Control

1. Introduction

Incorporation of Artificial Intelligence in automobile industry is highly demanding these years. Many researchers are working on driverless vehicle which is capable of human like intelligence. Autonomous vehicle parking [3, 6, 8, 9, 10, 11, 13] is ability of vehicle to park itself in given parking slot considering nearby static or dynamic environment and it is considered challenging problem.

Parallel parking has been widely discussed [1, 2, 4, 5, 6, 7] and researchers have provided techniques to solve the parallel parking problem. Parking of vehicle can be considered as a vehicle steering control problem. Parking problem

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10.1016/j.procs.2018.07.011

can be easily solved with offline path planning approach [1, 8, 9] but these methods have limitations of not considering dynamic nature of environment. In recent literature, soft computing based steering control mechanisms [2, 3, 4, 5, 6, 10] are developed and tested. Soft computing based approaches, in general provide real-time self-learning for system to meet objectives. These systems take feedback from environment and decide vehicle motion and step-size. Using fuzzy based approach, human driver like expertise can be developed in vehicle without much prior knowledge of environment. Auto vehicle parking based on fuzzy control with emphasis given on parallel parking [15] seems more promising than garage or diagonal parking due to requirement of less space and can be parked in multi-environment like streets, markets, society. Such parking can be very useful in metro cities facing real traffic issues.

In all earlier mentioned approaches for parallel parking, parking problem had been addressed with only static conditions of parking environment. In addition, major parking algorithms found in works of literatures have considered only single parking and strategies have not been considered for multiple parking scenario so far. In actual scenario, human driver has all expertise to mitigate possible collision during maneuverings of vehicle i.e. human can redirect vehicle by looking at nearby static or dynamic obstacles. Parking has also its own practical challenges. In our earlier work [15], problem of appearance of any obstacle or vehicle in between vehicle and parking area was highlighted. Sometimes, some manual driven vehicle may arrive and can be parked before given automated vehicle system reaches inside parking slot. For such situations, an intelligent system must be capable to take human like instant decision. No literature has given solution of adaptability provision during parking control. This paper addresses this problem and presents a novel hybrid approach including intelligent Navigation and Parking problems. Also, it extends and tests hybrid algorithm in multiple parking scenario where more than one parallel parking space is considered. It has also potential to implement in real-time vehicle and it can be fit in major parallel parking spaces.

This paper is organized as follows: Section 2 describes multiple parking scenario with necessary assumptions. Section 3 briefs navigation and parallel parking algorithms followed by proposed hybrid approach for parallel parking. Simulations for different environment cases are presented in section 4. Finally, concluding remarks and future scopes are given in section 5.

2. Multiple parking system in dynamic environment

In current scenario, parking seems potentially easy task for human drivers than automated vehicle. A human can look over dynamicity present in environment like other vehicle, obstacles, living animals etc. For any intelligent system mimicking such behavior, it is difficult task because of imprecise data available. Many researchers have presented solutions for parallel and garage parking problems way but not considered the scenario in dynamic situation where system starts parking and another vehicle is parked or obstacle appears before it completes. Following subsection details basic set up for proposed work.

2.1. Environment setup

Consider multiple parking environment as shown in Fig.1. It shows a parking environment including multiple parking slots with clear separation of parking zone and Non-parking zone (called as navigation zone). The Scenario includes 3 different parallel parking slots labeled as parking slot A, parking slot B and parking slot C. Once vehicle reaches to parking zone by means of navigation or offline path planning, it will search for empty parking slot(s). The vehicle will autonomously steer itself towards empty parking slot and park itself, as discussed in next sections.

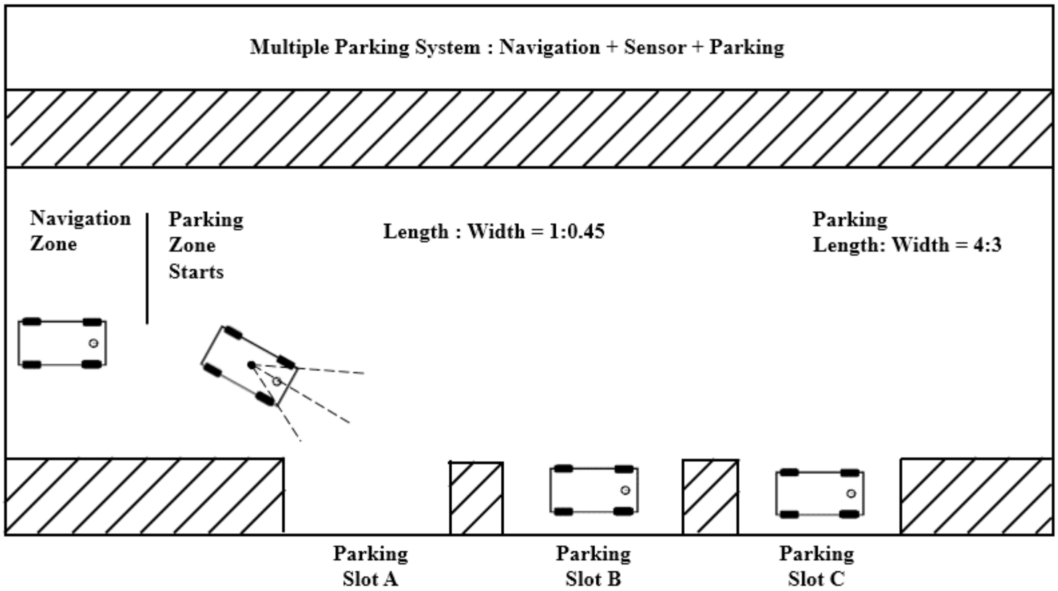

Fig. 1. Multiple parking system scenario

2.2. Car-like mobile robot (CLMR) model

A car-like mobile robot model (CLMR) is considered as depicted in fig.2. It is having four-wheeled mechanism that matches real automobiles. Dot circle in between front wheels indicates steering and front side of vehicle. Steering angle and rear wheel velocities are controlling parameter for this model. A vehicle is limited to turn its front wheels into left and right but they will remain parallel.

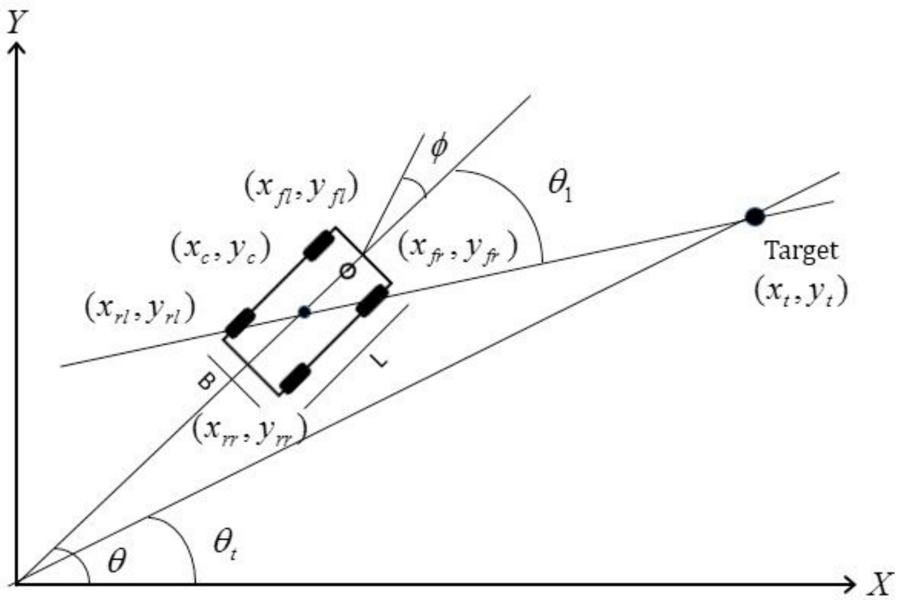

Fig. 2. CLMR model.

All respective parameters of the CLMR, as shown in fig. 2, are described as follows:

Nomenclature

(x_{fl}, y_{fl})	Position of Front Left Wheel of CLMR
(x_{fr}, y_{rl})	Position of Front Right Wheel of CLMR
(x_{rl}, y_{rl})	Position of Rear Left Wheel of CLMR
(x_{rr}, y_{rr})	Position of Rear Right Wheel of CLMR
(x_c, y_c)	Position of Centre of CLMR with respect to its length and width
(x_t, y_t)	Position of Target (if any)
θ	Orientation of Vehicle Body with respect to X axis
θ_t	Orientation of Target with respect to X axis
θ_1	Angle between CLMR body and Target
ϕ	Orientation of the steering-wheels with respect to the CLMR body i.e. steering angle
L	Length of CLMR
B	Width of CLMR

Considering angles with reference to positive X-axis, forward kinematics equations used for CLMR model are as follows:

$$\theta_{new} = \theta_{old} + \dot{\theta} * dt \tag{1}$$

$$x_{new} = x_{old} + v * \cos(\theta_{new}) * dt \tag{2}$$

$$y_{new} = y_{old} + v * \sin(\theta_{new}) * dt \tag{3}$$

$$v = (v_{left} + v_{right}) / 2 \tag{4}$$

Equations (1), (2) and (3) are kinematics equation used for synchronous drive when only steering angle is changed and rear wheels only roll simultaneously. For synchronous drive, velocity is assumed as constant. In case of differential drive mechanism, equation (4) is used to calculate angle, x-position and y-position updates in equations (1), (2) and (3); respectively.

3. Fuzzy based approaches for navigation and parallel parking

This section describes two individual fuzzy based systems, our earlier proposed navigation module [12] and also parallel parking module that is conceptually similar to as discussed in [2, 5] but modified significantly for actual implementation. Navigation based fuzzy system navigates CLMR from one point to another using sensory information. During its journey, CLMR calculates distance of nearby obstacles using range calculation algorithm discussed in [12]. Parallel parking based fuzzy system parks vehicle inside parking in either forward or reverse manner. Reverse parking is better option compared to forward parking when tight space available for parking [5]. Our proposed work addresses both forward and reverse parking scenarios. The basic flow of our work is presented fig. 3.

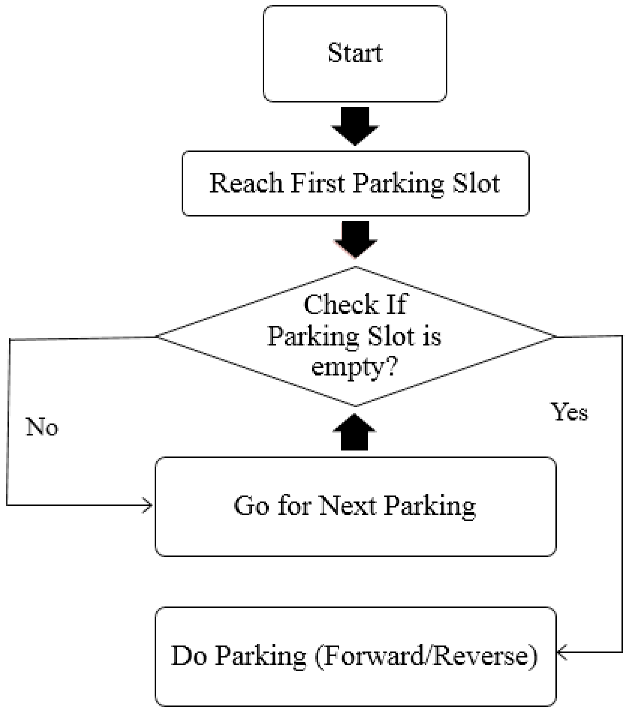

Fig. 3. General Approach for multiple parking scenario.

As shown in fig. 3, parking of CLMR is done in a sequential manner forwards or backwards depending on parking space. Three parking slots A, B, and C, as shown earlier in fig.1 are considered. CLMR is assumed to start from parking slot A and in sequence next parking will be slot B and slot C; respectively

3.1. Fuzzy based navigation

In earlier work, researchers have considered parking as a stand-alone problem which is many times not feasible in the actual practice. CLMR will perform navigation till it enters the parking zone. Fuzzy based navigation module incorporating 4 inputs (Left_Obs, Front_Obs, Right_Obs, Head_Ang) and 2 outputs (Left_Vel, Right_Vel) has been adapted from our earlier work [12, 14]. Few samples of fundamental rules used in navigation based fuzzy control are described in Table 1. Detailed rules and membership functions of fuzzy input and output can be found in [14]. For navigation module, differential drive mechanism as discussed in section 2, is used. CLMR reaches to its destination parking zone with avoiding any obstacles using fuzzy based behavior rules.

Table 1: Sample Fuzzy If – then rules for Navigation

If						Then	
Rule no.	Fuzzy Behaviour	Left Obs	Front Obs	Right Obs	Head Ang	Left Vel	Right Vel
1	Target Steer	Far	Far	Far	N	Low	Fast
2	Target Steer	Far	Far	Far	Z	Fast	Fast
3	Target Steer	Far	Far	Far	P	Fast	Low
4	Obstacle Avoidance	Near	Near	Far	N	Fast	Low
5	Edge Following	Far	Far	Near	P	Med	Med

3.2. Fuzzy based parallel parking

The main objective of this paper is to enable CLMR in parallel parking space effectively and successfully, without any collision. One of the methods for parallel parking is addressed by following fifth order polynomial path [2, 7] in parking space. It can be done via two ways: offline path planning [1, 8, 9] and online path planning [2, 3, 4, 5, 6, 10]. Online path planning is feedback based system where each motion step is based on environment information.

Many soft computing based techniques such as fuzzy and neural networks are popularly used in recent times for various applications including autonomous vehicles. The fuzzy based system used for parallel parking is described in this section. The proposed system constitutes 2 inputs i.e. vehicle orientation angle i1 and angle between vehicle and target i2 Based on two angle information. The system calculates steering angle φ as output using 49 linguistic rules given in fig.4 (a) and fig 4 (b). It uses seven different membership functions such as Negative Big (NB), Negative Medium (NM), Zero (ZE) etc. Detailed shape and information about fuzzy membership functions for input and output are given in [2]. Fuzzy rules are designed in such a way that vehicle can reach to final point of parking inside parking slot from its initial position by following fifth order polynomial path.

a

i2 / i1 Φ	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	NS	NM	NB	NB	NB	NB
NM	PS	ZE	NS	NM	NB	NB	NB
NS	PM	PS	ZE	NS	NM	NB	NB
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	PB	PB	PM	PS	ZE	NS	NM
PM	PB	PB	PB	PM	PS	ZE	NS
PB	PB	PB	PB	PB	PM	PS	ZE

b

i2 / i1 Φ	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	PS	PM	PB	PB	PB	PB
NM	NS	ZE	PS	PM	PB	PB	PB
NS	NM	NS	ZE	PS	PM	PB	PB
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NB	NB	NM	NS	ZE	PS	PM
PM	NB	NB	NB	NM	NS	ZE	PS
PB	NB	NB	NB	NB	NM	NS	ZE

Fig. 4. (a)Fuzzy rules for reverse parking (b) Fuzzy rules for forward parking

3.3. Proposed hybrid approach for parallel parking

This section discusses hybrid approach of navigation and parallel parking fuzzy systems described in earlier subsections 3.1 and 3.2. The hybrid approach is explained via flowchart in fig. 5. A hybrid system is developed where, vehicle dynamically swaps between parking and navigation modules according to environmental conditions. When vehicle starts parking in first empty slot, it checks for any object placed in that parking area via sensory information. If it detects presence of any vehicle or non-moving objects, it will initialize navigation algorithm and move towards second parking slot using navigation. Thus, advantage of navigation obstacle avoidance skill can be integrated with parallel parking for detecting vehicle parked inside parking space. After reaching to the second slot, it again switches to parking algorithm and repeats process until it finds empty slot and parked. Vehicle does not have any priory information regarding parking availability and it takes decision entirely based on the available environment data. In this way, dynamic control for obstacle avoidance in parking problem is also incorporated.

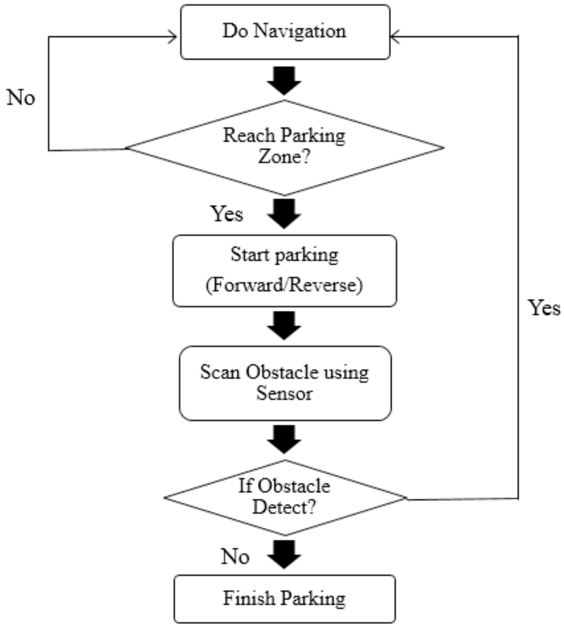

Fig. 5. Flowchart of proposed Hybrid solution

While executing parking module and trying to reach towards parking slots; if at any stage CLMR finds any of sensor distance less than some threshold; system identifies presence of obstacle in parking slot and algorithm is switched to navigation module from parking module. Thresholds values for distance measurements in forward parking module, as well as reverse parking are set, empirically.

4. Simulation results

In order to verify efficacy of proposed hybrid approach, multiple parking scenario (as earlier shown in fig.1) is created. Different cases are considered to check the ability of proposed system to park CLMR using forward parking, reverse parking, redirection in case of non-feasibility etc. A Matlab environment of size 20 by 20 m is created with combination of parking slot and obstacles. Each parking slot is considered having length to width ratio as 4:3 m. Vehicle length: width ration is taken as 1: 0.45 to match with real time hatchback vehicle dimension. The velocity of CLMR is taken as 1 m/s and vehicle is assumed to be equipped with ultrasonic sensors mounted on both front and rear side to measure nearby obstacle distances. Also environment surface is assumed as flat.

4.1. Case 1: Parking when slot A is empty

In this case, parking slot labeled as “A” is assumed to be empty. Parking slot “B” and “C” are assumed to have parked already. CLMR is assumed to start from left side and reaches first to parking slot A. Fig. 6(a) and fig. 6(b) shows simulation of forward parking and reverse parking, respectively when slot A is available for parking. A red dot in vehicle represents front side of vehicle. The simulation shows successful parking.

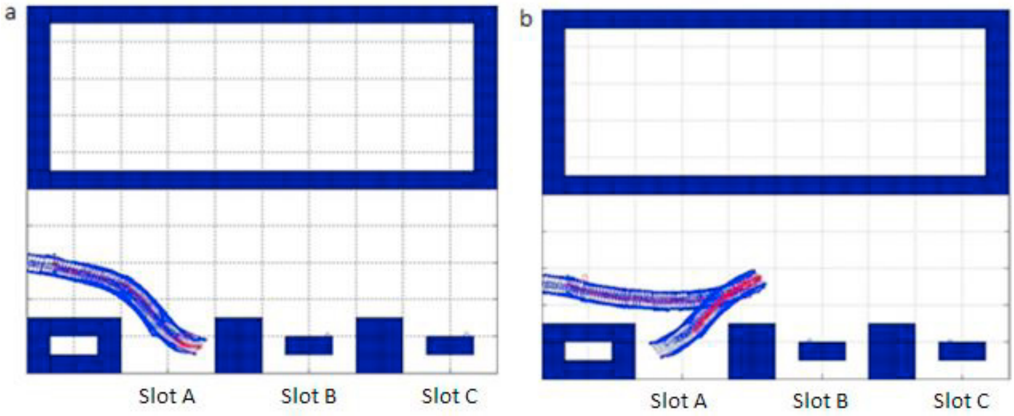

Fig. 6. Case 1: a) Forward parking b) Reverse parking

4.2. Case 2: Parking slot A is full and slot B is empty

In this case, parking slot labeled as “A” is full and Slot "B" is assumed to be empty. When, CLMR enters from left side, it checks for feasibility in parking slot “A” but as soon as finds the vehicle already parked (due to sensor distance going below threshold set for both forward as well as reverse) it switches to navigation module and reaches to parking slot “B”. As slot “B” is empty CLMR, successfully parks inside it by either following forward parking, as shown in fig. 7(a) or parks inside it following reverse parking, as shown in fig. 7(b); depending upon the availability of space and targeted parking location.

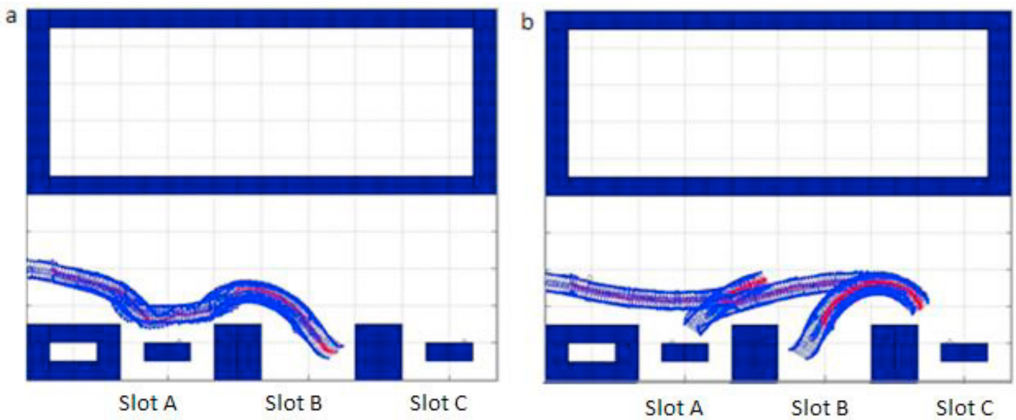

Fig. 7. Case 2: a) Forward parking b) Reverse parking

4.3. Case 3: Parking slot A and B are full and slot C is empty

In this case, Parking Slots "A" and "B” are assumed full and Parking Slot C is empty and other assumption kept same; simulations results are as shown fig. 8(a) and fig. 8(b), respectively.

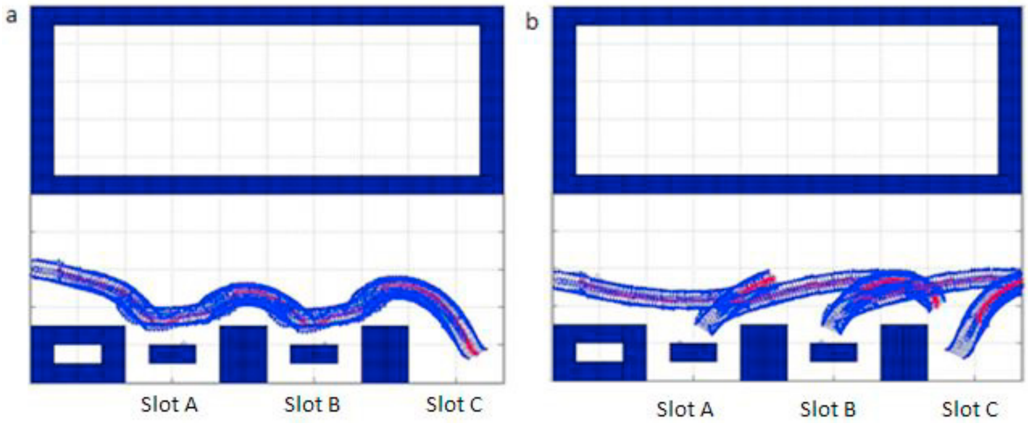

Fig. 8. Case 3: a) Forward parking b) Reverse parking

4.4. Case 4: All Parking slots are full

In case 4 depicts the case in which all parking slots are assumed to fully parked. Vehicle searched for every possible parking slot and eventually forwards to another available slot. Hereafter third slot next available slot can be considered as extension of algorithm. For this simulation only three slots are taken which can be extended with n number of slots. Fig. 9(a) and fig. 9(b) shows vehicle simulation when no parking is available for parking.

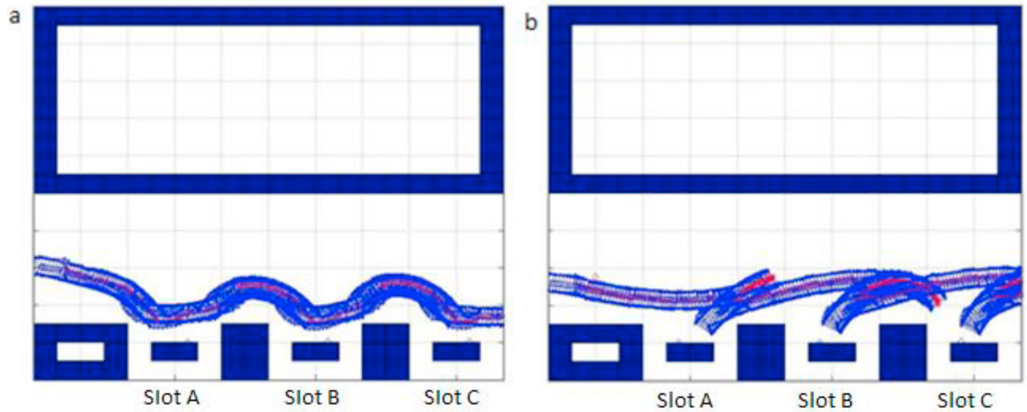

Fig. 9. Case 4: a) Forward parking b) Reverse parking

4.5. Behavior analysis of CLMR during case 4

To understand the behavior of CLMR in details and visualize swapping of algorithm during its runtime one sample case i.e. case 4 forward path is shown in fig. 10. Total six breakup points (1 to 6) are shown in fig. 10. CLMR enters parking zone from left side of point 1. Part 1 draws boundary between Navigation and Parking. To the left side of point 1, region can be considered as navigated path (outside parking area) for CLMR. Even though this region (left of point a) is shown as very short, path for navigation it can be very big in actual. It is due to the fact that our aim is to highlight behavior of CLMR in parking area. Point 1 to Point 2 path is entirely parking. At "2", system detects vehicle already parked inside parking area and hence, switches to navigation and sets its next target as "3". Part 2 to part 3 is entirely navigation. Similar switches happen at part 4, part 5 and part 6.

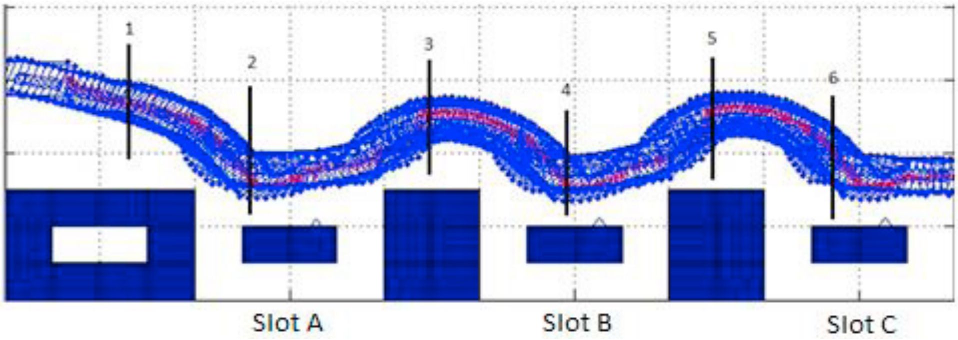

Fig. 10. Motion path of Case 4 in Forward parking

5. Conclusion

Simulation results demonstrate efficacy of proposed hybrid approach for multiple parking scenario. CLMR is able to park vehicle using forward or reverse parking strategy depending upon parking space available. Dynamic swapping between navigation and parking algorithm extends level of intelligence in CLMR compared to earlier work. It uses obstacle avoidance capability of navigation algorithm which performs dynamic control while, executing parking. Behaviour analysis helps to understand the switching strategy and details of parking. Threshold for switching can be modified as per the requirement. The proposed fuzzy intelligent system can be implemented on real time vehicle for practical trials.

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