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Development of a Hierarchical Driver Aid for Parallel Parking Using Fuzzy Biomimetic Approach

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The objective of this article is to present the design method of a hierarchical driver aid which is designed to guide the driver of a vehicle to perform parallel parking maneuver. The development philosophy of the system is based on biomimetic model where the designer of the model does not need to be aware of either vehicle dynamics or kinematics. The developed system is based on fuzzy logic and makes its decision based on visual information coming through two low-resolution cameras placed at strategic locations of the vehicle. System evaluates critical parameters and gives real-time, on-the-fly advice to driver, based on position of the vehicle and the intended parking space. The approach is very similar to an expert observing the driver and giving interactive advice about what to do to achieve acceptable parking. The article explains design philosophy, development method used for extracting fuzzy rules, implementation and test results of the developed system.

Keywords: driver information system, fuzzy logic, image processing, intelligent control, interactive systems, real time system, road vehicle control, biomimetic systems

1. Introduction

Ever increasing traffic is becoming more and more demanding on the driver. Fortunately, embedded computer technology and mechatronics has been providing drivers with affordable modern driver aids. Sophisticated intelligent driver aids like GPS, vehicle stability control have become economically feasible and found their ways into today's modern vehicles.

Fuzzy logic has proven itself as a very useful tool for automotive industry and many luxury and safety features are based on fuzzy logic. Fuzzy anti lock brakes and fuzzy logic based transmission shifting have proven to be useful features. They are developed with reasonable effort using the tools and concepts provided by fuzzy logic [1, 2].

As the computer and vision technology is improving, we have started developing new category of driver aids that we have not seen before. The new driver aids which are called copilots, will be providing aid to driver actively or passively [3]. These tools are expected to appear in the coming years and have many different applications [4,5]. Vehicle path planning, curve warning systems, adaptive speed regulations are such aids which are likely to appear in next generation modern vehicles.

The type of interactions between driver, copilot, and the vehicle bring important issues which require serious considerations while designing modern driver aids. Currently there are two models of approaches to this three way interaction between vehicle, driver and copilot [3].

1. Hierarchical (vertical) structure approach,
2. Heterarchial (horizontal) structure approach.

In hierarchical structure approach, the driver is superior in hierarchy, and copilot provides advice to the driver only. In this approach, the driver is the sole decision maker and has the option to take or leave the advice provided by the copilot. This approach is known as "open loop mode" or "Driver Warning Mode".

In heterarchial approach, copilot and driver have the same level in hierarchy and can make the decision together [6, 7]. This approach is known as “closed loop mode” where the copilot may actively participate in correction of the vehicle guidance (Vehicle Control Mode). Some of the systems adapt a hybrid approach where the driver is initially warned only with no corrective action from the copilot (Driver Warning Mode). But if the driver continues to drive in an unacceptable way, copilot goes into heterarchial mode and makes the necessary corrections to bring the vehicle into appropriate driving conditions (Vehicle Control Mode).

In this study, we have designed a hierarchical tool to help the driver to perform parallel parking maneuver. The tool is based on visual processing of information coming from two cameras and works with fuzzy rules of operation. One of the contributions of the paper is the way fuzzy rules are extracted from the behavior of an expert driver.

2. Parallel Parking Problem

Parallel parking of a vehicle is considered a difficult maneuver to master by many drivers. Looking at it from an engineer’s point of view, it is considered a multi objective optimization problem, where several distance parameters need to be satisfied simultaneously for a successful parking.

2.1. Models Used for Vehicle

Kinematic model of a front wheel steered vehicle is given by de Lope and Maravall and shown in Figure 1[8].

$$\dot{x}(t) = v(t)\cos\theta(t)$$
$$\dot{y}(t) = v(t)\sin\theta(t)$$
$$\dot{\theta}(t) = v(t)/L\tan\phi(t)$$

Where (x, y) is the center point of rear axle of vehicle; θ is the direction of heading of vehicle; v is the speed of vehicle; L is distance between front and rear axle centers, and ϕ is the angle of steering wheel with respect to the orientation of the vehicle is heading.

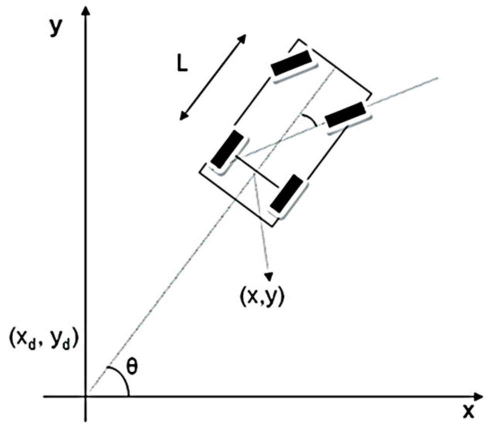

Figure 1. Kinematic model of vehicle.

In this model, (v, ϕ) are the parameters that are under control of the driver and (x, y, θ) are parameters that indicate the state of the vehicle. The discrete versions of the formulas above are given as follows, where T_S is the sample time [8]:

$$x_{k+1} = x_k + v_k T_S \cos\theta_k$$
$$y_{k+1} = y_k + v_k T_S \sin\theta_k$$
$$\theta_{k+1} = \theta_k + (v_k/L)T_S \tan\phi_k$$

with the limitation that steering angle has to be lower than maximum physically allowable value for the vehicle;

$$0 \leq \phi_k \leq \phi_{\max}$$

One of the objectives of the parking process is to position the car in the desired spot (x_d, y_d) and the other objective is to orient the car in line with the parking position θ_d. Mathematically, this can be expressed as minimization of two indexes;

$$J_1 = \frac{1}{2}[(x - x_d)^2 + (y - y_d)^2]$$
$$J_2 = \frac{1}{2}[(\theta - \theta_d)^2]$$

Where x, y and θ indicate the final position of the vehicle and the orientation in the parking bay. J_1 reflects how well the vehicle is centered in the parking bay and J_2 indicates how well the vehicle is oriented in the parking bay. Minimization is supposed to be achieved by using control variables available for the driver, namely speed and steering orientation (v_k, ϕ_k). Of the two variables, v_k is not likely to be changed aggressively by the driver and it can be assumed constant during the parking process. The parameter that affects the quality of parking most is the steering orientation ϕ_k. Minimization of the two indexes with respect to ϕ can be expressed as follows:

$$\phi(t) = -\mu_1 \frac{\partial J_1}{\partial \phi} - \mu_2 \frac{\partial J_2}{\partial \phi}$$

where μ_1 and μ_2 are the weights attached to the goals J_1 and J_2 indicating how important the goals are. Discrete version of this formula is given as:

$$\phi_{k+1} = \phi_k - \mu_1 \frac{\partial J_1}{\partial \phi}\bigg|_{\phi_k} - \mu \frac{\partial J_2}{\partial \phi}\bigg|_{\phi_k}$$

Even though minimization of the total duration of the process is another goal that needs to be minimized, the weight attached to this goal is usually small enough to be ignored in the calculations. According to the above formula, optimization is achieved by adjusting steering incrementally, to satisfy both J_1 and J_2 simultaneously.

In this paper we have not used the above derived mathematical model. Rather, the model is developed using fuzzy approach by mere observation of the expert driver behavior. The fuzzy model developed for the vehicle does not contain such formulas, but the rules describing behavior of vehicle under different conditions. However, for determination of quality of parking, we have adapted the J_1 and J_2 parameters developed by the above mathematical model.

2.2. Approaches to Parallel Parking

Like many real world-engineering problems, parallel parking problem is considered a difficult problem to automate using classical mathematical optimization techniques. Currently there are two different approaches adapted by researchers [9].

1. Path planning approach,
2. Skill based approach.

In the path planning approach, parking area, driving path, vehicle dynamics are taken into consideration and a path is planned before the vehicle starts moving. Then necessary control commands are generated to move the vehicle in the planned path. Several researchers [10-13] have studied the path planning approach. In these approaches, parking space is scanned, analyzed and a sinusoidal path that leads to the destination is generated. Once the vehicle is within the bay, what other maneuvers should be done is also planned in advance. The path planning approach is considered "open loop" since movement instructions are generated before the move starts. This approach cannot cope with the errors introduced during the execution or problems due to vehicle dynamics.

In the second approach, skill based approach, soft computing tools are used to generate instructions to guide the vehicle to the intended destination. In this approach, there is no reference path and the instructions are provided based on relative orientation and position of the vehicle with respect to the parking position. Skill based approach has been very popular and studied by many researchers. Most of these researches are based on ultrasonic sensors and directions generated using neural networks, fuzzy logic and genetic algorithms [14-20]. Researchers like Jiang have combined path planning and skill based approaches in their approach where the parking space is first scanned, then the vehicle is positioned and maneuvered into the parking space [21, 22].

Few researchers used visual guidance to guide the vehicle into the parking space. Daxwanger et al. [23], used the image from camera to study the location of the parking space and used neural networks for calculating the necessary steering angles. De luca et al. and Bercemeier [24, 25] have experimented with visual guidance and parking although not particularly focusing on parallel parking issue. Recent studies by Gomez-Bravo et al. combined artificial intelligence and β-spline curves to generate smooth path for parking [26, 27]. In their interesting approach, de Lope and Maravall have used genetic algorithms to generate path for parallel parking [8].

Most of the approaches listed above use ultrasonic distance sensors, for collecting distance information from perimeters of the parking spot. Some researchers like Chen and Feng have used a camera and soft computing tools to guide a model vehicle autonomously into parking spot [28].

The automotive industry has recently been manufacturing vehicles with automatic parallel parking feature. One of the manufacturers integrates information coming from sonar sensors with the image coming from rear view camera to guide the vehicle into parallel parking position automatically. In this case, image is used as a way of asking the driver to determine the location and boundaries of the parking spot [29]. After the initial settings are done on the image of the parking location, the vehicle rears itself into the parking spot automatically.

Even though fuzzy logic and vision are used in many prototypes, visual information is used as supplemental to other sensor information since use of a single camera typically limits the scope of vision in full size vehicles. A single camera placed over a small prototype vehicle may see the limits of the parking space, but it is quite unlikely to get an unobstructed view of the parking bay when it is used on a full size vehicle. In our approach we decided to use two cameras to mimic the expert driver giving guidance to driver for successful parking execution.

Biomimetic is described as the art of designing by mimicking biological systems. In biomimetic approach there is a direct coupling between perceptions and actions without knowing the complexity of the underlying mechanism [8]. It is observed that an expert driver guides the novice by observing the distance from the curb and the parked vehicles. There is no need to know the vehicle dynamics, exact length of either the vehicle or the steering angle. Expert can guide simply by relying on his perception of distance from surrounding vehicles and curb. Our approach in this study has been to mimic and expert for the guidance operation.

Since the view from both front and back is required at different times, we typically see expert changing his/her position to get better view of back or front. In our approach two cameras are placed, one at the front and one at the back to get both views simultaneously and feed the distance information to a fuzzy logic system to mimic decisions of an expert driver. Low resolution cameras are selected deliberately to reduce the computational complexity of image processing. Unlike parking bay recognition done in other camera based approaches, only few crucial parameters are extracted from camera images through very efficient image processing algorithms. Since the system is intended as a driver aid, a suitable human-machine interface (HMI) system is designed to relay generated advice to the driver. The following sections explain the approach in detail.

3. Overview of the System

Parallel parking driver aid system, which will be referred to as "parking aid" in short, is a system which utilizes visual image coming from two strategically located low resolution cameras to generate instant advice for the driver toward successful parallel parking maneuver. Human machine interface (HMI) is provided through an LCD screen located over the dashboard which provides instructions in graphical form about what the driver should do for an acceptable parking. The system is based on fuzzy logic and information about the lateral and longitudinal positions of the vehicle acquired through processing the visual image provided by the cameras. Figure 2 shows the block diagram of the system.

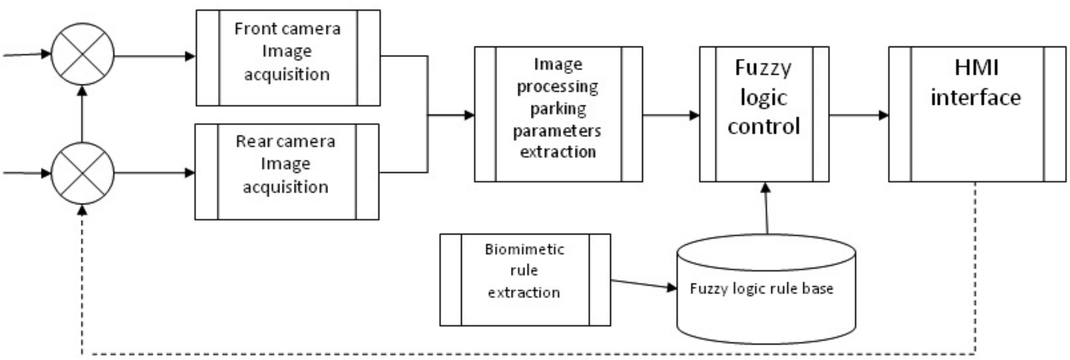

Figure 2. Block diagram of the biomimetic vision-based parallel parking system.

The system is designed to operate by relying on visual information received from two cameras located on the vehicle. The cameras need to have wide angle of vision, and should be oriented in a specific manner in order to extract critical information necessary for generating appropriate advice for the driver. Over the course of the project, different camera locations and different angles of visions are tested and we found a combination which produced the most acceptable view with reasonably easy installation location on vehicles. Single camera solution has been tested, but found to be inadequate for providing necessary information. Figure 3 indicates the position and orientation of the cameras on the vehicle.

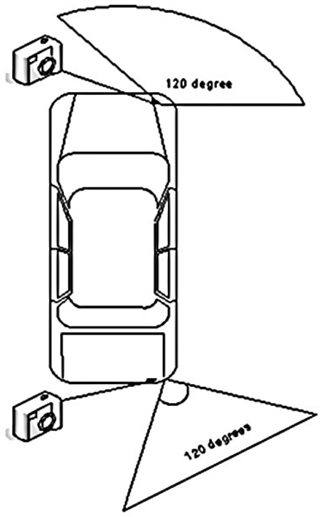

Figure 3. Parallel parking driver aid system uses two wide angle cameras placed at the corners of the vehicle to visualize necessary parameters.

The cameras are fixed on front and rear bumpers of the vehicle, with special orientation shown in Figure 3. The exact position of the camera in different vehicles may vary slightly due to existing physical obstructions over the body of the vehicle. Figure 4 shows the way cameras are attached to one of the test vehicles (Toyota Landcruiser, 2002). The positions of the cameras are selected to provide optimum views of curb and vehicles located at the front and at the rear of test vehicle.

Operation of the system requires parking area to be sufficiently illuminated. So for nighttime operation the parking area needs to be sufficiently illuminated for acquiring visual image of the parking space. Tests are done in parking areas with clearly marked demarcation lines as well as parking areas where demarcation lines are either not visible because of parked vehicles or do not exist at all. When there were no demarcation lines in the parking lot, visual information was extracted from the distance of curb stones and from the image of vehicles parked in front and behind. These cases were clearly more challenging, especially in low light situations for the vision processing system. However, it is understood that these conditions are considered challenging even for seasoned human drivers. Glare from the sun is found to be very detrimental for acquiring images, as a result, hoods were installed to cameras to prevent glare from the sun.

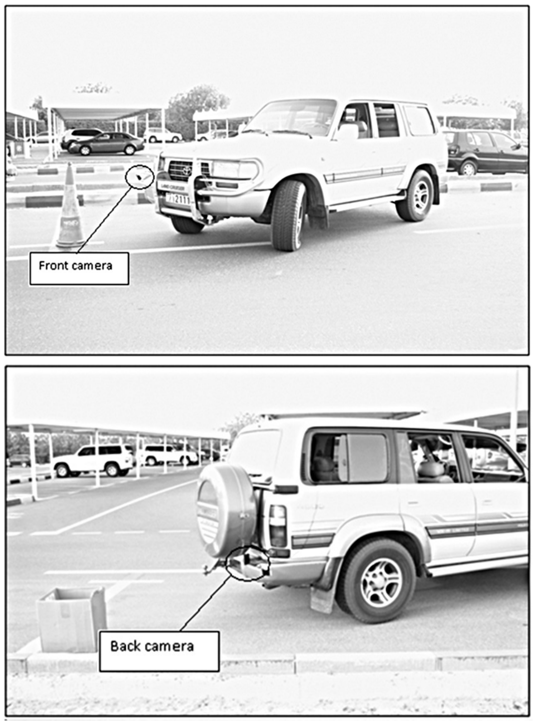

Figure 4. Locations of the front and back cameras on the test vehicle.

3.1. Operation of the System

Parallel parking is considered one of the hardest driving skills for novice drivers to master. Parallel parking maneuvers are made rearward since this allows placement of the non-steerable rear end of the vehicle in the parking place first. When performing parallel parking, there are three important parameters that need to be monitored carefully. These parameters are:

- D_f: Distance between the vehicle and the car in front,
- D_r: Distance between the vehicle and the car at the back,
- D_{lf}: Lateral distance between the vehicle and the curb at the front side.
- D_{lr}: Lateral distance between the vehicle and the curb at the rear side.

These parameters are indicated in Figure 5 and they all together determine the quality of parking factors J_1 and J_2 which were derived in Section 2. The relationship between those parameters can be expressed as follows:

$$x_d = \frac{1}{2}(D_f + D_r)$$
$$y_d = \frac{1}{2}(D_{lf} + D_{lr})$$
$$\theta_d = \sin^{-1}\frac{(D_{lf} - D_{lr})}{L}$$

Getting all these parameters simultaneously using a single camera is not feasible, even with wide angle lenses. Therefore, two separate cameras are used for getting these parameters. Both cameras are oriented to visualize both the distance from the curb and distance from the vehicle at front or rear simultaneously. Both cameras are oriented downward showing the other cars, the street, the edge of the curb and other obstacles on the way.

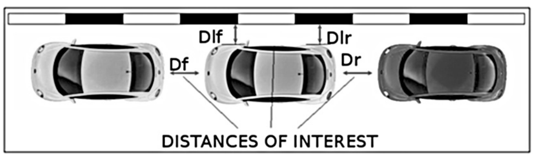

Figure 5. The distance parameters.

In Section 2.1 the quality of parking formula was derived as;

$$\phi(t) = -\mu_1\frac{\partial J_1}{\partial \phi} - \mu_2\frac{\partial J_2}{\partial \phi}$$

During the implementation of the system, the orientation of the vehicle is considered less important than the distance from curb and vehicles and importance coefficients are determined as:

$$\mu_1 = 1, \qquad \mu_2 = 0$$

As a result of this assumption, only D_f, D_r, and D_{lr} parameters are acquired from the images. D_{lf} parameter is ignored and not used in the operation.

3.2. Image Processing

The fuzzy parking aid system automatically starts capturing images once it is activated by the user. Figure 6 shows the simple block diagram of the system design. The video stream of images coming from the cameras is fed to an image processing unit, which processes the image to calculate the distance parameters and passes them on to the fuzzy logic unit which makes appropriate decisions and presents the output as guidance advice to the driver for parallel parking. In the prototype, two commercial low cost USB cameras with 30 fpm frame rate with resolution of 320 × 288 pixels are used for providing video images. The lenses are replaced with wide angle lenses to provide 120 degree wide angle visual coverage. A notebook computer loaded with MATLAB©, Image Processing Toolbox and Fuzzy Logic Toolbox extensions are used for analyzing image and constructing fuzzy inference system. The cameras

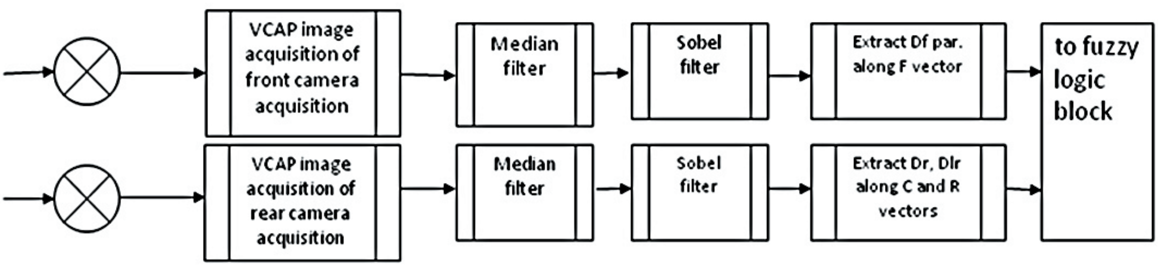

Figure 6. Block diagram of image processing part.

are interfaced to MATLAB© by an image capture tool which can support up to 6 USB cameras simultaneously [30, 31].

The captured image is processed to acquire distances from front and back vehicles as well as lateral distances from the curb. Figure 7 shows the real image and the processed image of rear camera with the involved distances from curb (C) and the rear vehicle (R). Front camera image and the distance parameter measured is indicated as (F) in the figure. Images received from the two USB cameras are treated as two independent streams of images for real time processing. The images in both streams first go through two dimensional median filtering where the images are smoothed to get rid of noise in the scene. This is done by taking the median value of 5×5 neighborhood pixels for each pixel in the original scene. As a result of this process, the smoothed image contains only large objects of interest. The second step in processing is applying edge detection procedure to detect edges of the objects in the scene. Edge detection step of the process is done by using Sobel filter. A dynamic threshold limit of contrast change is determined by averaging the background color and applied to the image. The level above this threshold is accepted as legitimate object edges. The process of applying threshold further reduces the noise in the image. Noise cancellation and edge detection is done by using standard tools provided by MATLAB© Image Processing Toolbox.

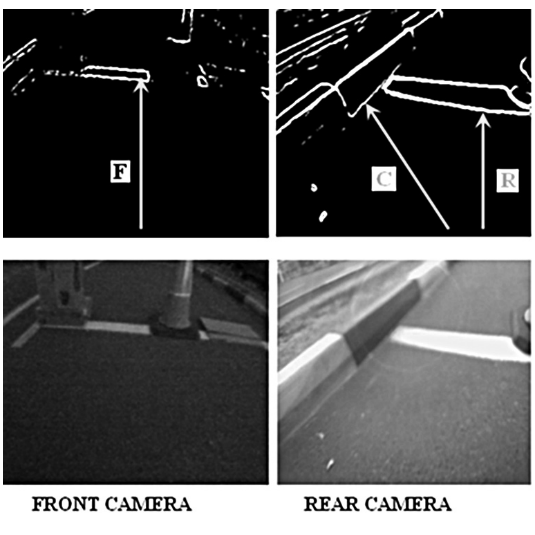

Figure 7. Front and rear camera images and the parameters measured along vectors F, C and R.

The edge detection process converts the image to a binary image with 0's and 1's. (0 corresponds to black and 1 corresponds to white in the matrix.) Next step in the image processing is measuring the pixel distance of the objects in the scene by counting pixels in the specific predetermined directions. Rear camera images are used for getting two distance parameters as shown in Figure 7. The straight up vector (R), measures the distance of the object or the available space behind the vehicle, D_r, and the 45 degree angled vector (C) measures the distance from the curb, D_{lf}. Both measurements are done by using simple trigonometric calculations or by counting pixels until we reach the edges indicated by white pixels. The magnitude of the distance vectors is used as the distance parameters in the latter portions of the system. A special MATLAB©routine is developed for counting number of pixels in the required direction until change in background color is detected. These counts are labeled accordingly as D_f, D_r, and D_{lr}.

3.3. Fuzzy Inference Systems

Fuzzy logic block of the system makes decisions based on the rear, front and curb parameters generated by the image processing block. Using approach adapted by most expert drivers, the parking maneuver is done in two distinct steps. Expert drivers usually drive the car backwards into the parking bay and then drive the vehicle forward to correct the orientation of the vehicle. We have designed the fuzzy logic inference system to mimic this behavior. Since expert driver approach is to do the parking in two distinct steps, we have used two different fuzzy logic systems to capture actions done in these two steps. First, fuzzy logic system guides the driver from the initial position to a halfway position where the rear end of the vehicle is placed in the parking space, while the front end of the vehicle is still partially outside the parking bay.

This part of the process is called Stage 1 operation where the beginning and ending positions are shown in Figure 8 as positions A and B.

The ending position in Stage 1 is not an acceptable orientation for parking, so Stage 2 makes the final corrections to put the vehicle completely in the parking position. Position B is

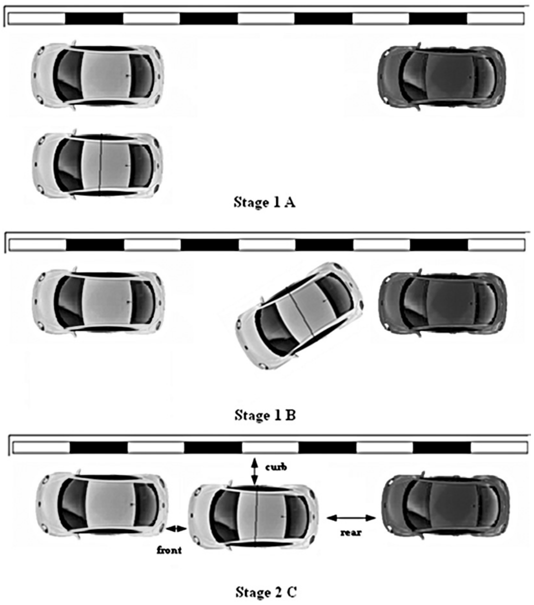

Figure 8. Beginning (Stage 1 A) and ending (Stage 1 B) positions of Stage 1 control. Stage 2 starts where Stage 1 ends (Stage 1 B). Ending position of Stage 2 is labeled as Stage 2 C.

the beginning position for Stage 2 and position C is the ending position. The distance from the curb in position C indicates the quality of parking. (The closer the better.)

Stage 1 Fuzzy Inference System

Both Stage 1 and Stage 2 fuzzy logic systems use the same linguistic input variables *frontCar*, *rearCar* and *curb* to operate. These input variables are shown in Figure 9.

Fuzzy logic inference systems work with fuzzy variables, membership functions and fuzzy logic rules. More information about fuzzy logic can be found in many references available [2].

Stage1 fuzzy inference system is responsible for bringing vehicle from initial position indicated as Stage 1 A to intermediate position shown as Stage 1 B in Figure 8. The membership functions for fuzzy input variables "*frontCar*", "*rearCar*" and "*curb*" are indicated as A, B, C in Figure 9. Fuzzy input variables "front" and "rear" have single membership functions labeled as "*close*" as shown in Figure 9 A and B panels. The fuzzy variable "*curb*" has five membership functions named "*close*", "*trigger close*", "*middleIN*", "*middleOUT*", and "*far*" which are indicated in panel C of Figure 9.

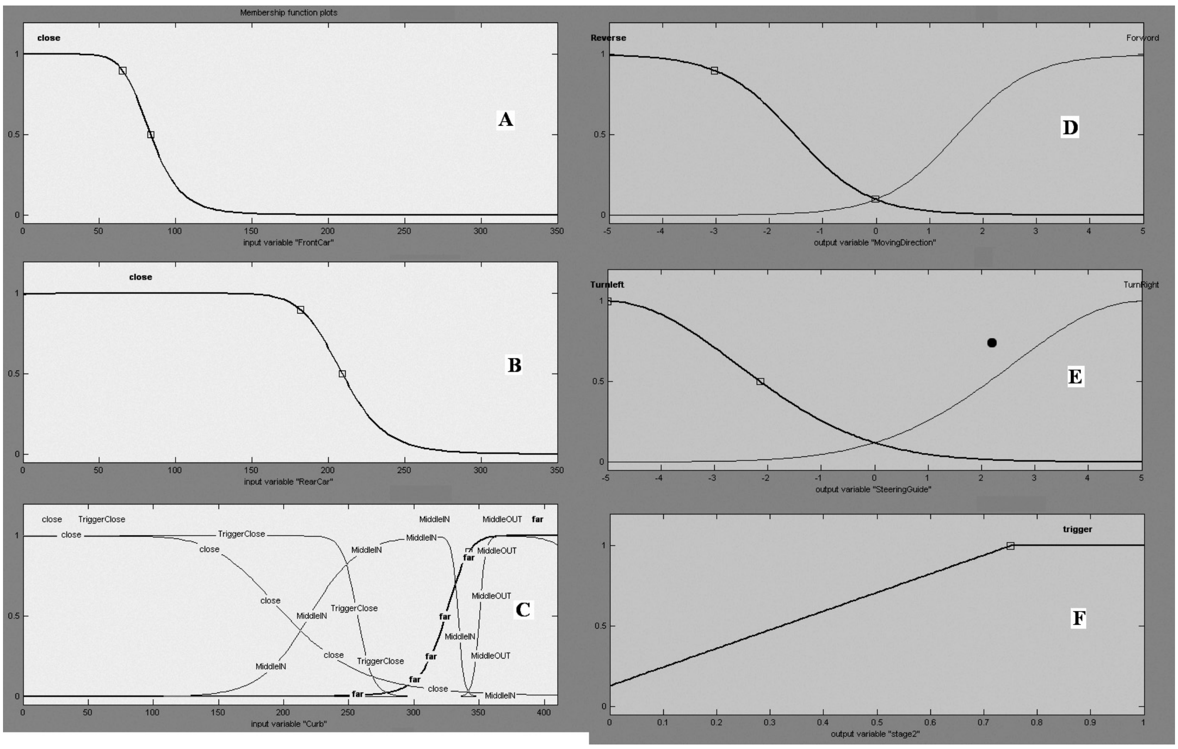

Figure 9. Membership functions for fuzzy input and output variables for Stage 1 inference system.

There are three output variables designed for the Stage 1 fuzzy inference system, labeled as "*movingDirection*", "*steeringGuide*" and "*trigger*". "*movingDirection*" and "*steeringGuide*" are the two parameters displayed by the Human Machine Interface LCD screen of the system to the vehicle driver and can be considered as the outputs of the Stage 1 system. The other output parameter of Stage 1, which is called "*trigger*" is not displayed to the driver, but it is used for initiating the start of the Stage 2 fuzzy inference system. "*trigger*" fuzzy variable is indicated in panel E in Figure 9. These two output parameters "*movingDirection*", "*steeringGuide*" and their associated membership functions are indicated in panels D and E in Figure 9.

Stage 2 fuzzy inference system is initiated by the trigger output of the Stage 1 and it is a completely independent inference system. The variables of this inference system are similar to Stage 1 inference system but fuzzy rules are completely different from the rules of Stage 1. Once the Stage 2 inference system is triggered, the driver instructions are generated and HMI screen is controlled by this stage.

The fuzzy rules for the Stage 1 are as follows:

- If (*Curb* is *far*) then (*MovingDirection* is *Reverse*) (1)
- If (*Curb* is *far*) and (*RearCar* is not *close*) then (*SteeringGuide* is *TurnRight*) (*MovingDirection* is *Reverse*) (0.9)
- If (*Curb* is *MiddleOUT*) and (*RearCar* is not *close*) then (*SteeringGuide* is *TurnRight*) (*MovingDirection* is *Reverse*) (0.9)
- If (*Curb* is *MiddleIN*) and (*RearCar* is not *close*) then (*SteeringGuide* is *Turnleft*) (*MovingDirection* is *Reverse*) (0.9)
- If (*FrontCar* is *close*) then (*MovingDirection* is *Reverse*) (1)
- If (*RearCar* is not *close*) then (*MovingDirection* is *Reverse*) (1)

Stage 2 Fuzzy Inference System

Stage 2 uses the same fuzzy variables "*curb*", "*rearCar*", and "*frontCar*". The membership functions of this stage have similar variables, but the shapes of the membership functions are quite different. Fuzzy rules for Stage 2 are as follows:

- If (*FrontCar* is not *close*) and (*Curb* is *close*) then (*SteeringGuide* is *TurnRight*) (*MovingDirection* is *Forward*) (1)
- If (*FrontCar* is not *close*) and (*RearCar* is *close*) then (*SteeringGuide* is *TurnRight*) (*MovingDirection* is *Forward*) (1)
- If (*FrontCar* is *close*) and (*RearCar* is not *close*) then (*SteeringGuide* is *Turnleft*) (*MovingDirection* is *Reverse*) (1)

The output variables of Stage 2 fuzzy inference system are exactly the same as variables of Stage 1 fuzzy system.

3.4. Biomimicing an Expert Driver's Approach to Parking

Designing equipment by emulating interactions that occur in nature is called biomimetic approach of design. The basic idea of biomimetic is to observe natural interactions, understand the mechanism and then design new equipment on these bases. Velcro is one of the well known products designed by biomimetic approach by copying hooks on a natural burr. Study of bones resulted in design of lighter yet stronger materials. Using this approach, the behavior of an expert driver is studied to come up with a method of parking that does not need to know the kinematics of the vehicle or the exact size of the parking bay. In a sense, all fuzzy systems are designed to mimic an expert by using appropriate rules. But in this case, the behavior of the expert is observed carefully and fuzzy rules of the inference systems are extracted from the observations alone. Since rule generation is done by observation, authors' believe this can be considered as biomimetic approach of rule generation.

Fuzzy systems operate by capturing experience of a skilled human expert using fuzzy decision rules and membership functions and reproduce these decisions when the system operates. In this study, in order to capture the experience of an expert driver, the cameras were set up in the designated locations of the test car and the images were recorded while the test vehicle was being parked manually by the expert driver. Later recorded images from front and rear cameras are processed by image processing routines developed for measuring D_f, D_r, and D_{lr} parameters. The measured parameters are plotted with respect to time, to see the relevance of these parameters with respect to each other. The typical parking operation took around 70 seconds and the parameters recorded during this session are shown as a time series Figure 10. Horizontal axis of the graph shown in Figure 10 indicates real time in seconds. Real time image frames coming from front and rear cameras are recorded and displayed for 70 seconds in the figure. Even though cameras provide images at a rate of 30 fps, due to space considerations only one image per second is displayed in the figure. Sample frames received from cameras are labeled and shown in Figure 11.

Images labeled from one to eight are for Stage 1 of the operation where the vehicle is reared into the parking bay, and the images labeled 9 and 10 are frames of Stage 2 of the operation where the posture of the vehicle is corrected. The actual video frame images corresponding to these numbers are shown in Figure 11.

As the images are received from cameras, image processing routines extracted the distance parameters from the images. The vertical axis of Figure 10 displays those distances calculated from the images. When the images and the recorded parameters are analyzed carefully, it is apparent that initial values given by the image processing routine for variable D_f, "*front*", (parameters 1 to 6) are noisy and have no meaningful value. Close inspection of the corresponding front camera images reveal that this indeed should be expected since those images do not really have a target to measure distance. (See front camera frames 1 to 6 in Figure 10.) "*Rear*" distance measurement parameter, D_r, is also very noisy at the beginning of stage 1 action for the same reason. (see frames 1 and 2.) But the "*curb*" distance parameter, D_{lr}, is very stable since the target is clearly in sight. (See "*curb*" parameter for frames 1 to 10 in Figure 10 and back camera views in Figure 11.)

The fuzzy rules of Stage 1 are designed in such a way that designed inference system initially depends on the reliable "*curb*" parameter, D_{lr}, and when the curb distance decreases to a certain value, the "*front*", D_f, and "*rear*", D_r, parameters are used. By that instant, both "*front*" and "*rear*" parameters have clear targets in sight and start giving reliable results.

Parameter 6 in Figure 10 marks a very important decision instant, where the expert driver steers the wheels from full right to full left. After this instant, the distance from the front car, "*front*", D_f, seems to increase and the distance from rear car, "*rear*", D_r, seems to decrease. To capture this instant of decision in our fuzzy system, fuzzy membership values "*middleIN*" and "*middleOUT*" are used. The "*curb*" membership functions "*middleIN*" and "*middleOUT*" are sculpted to capture this instant of decision and are indicated in panel C of Figure 9.

As it can be seen from the discussion above, almost all rules and parameter values are extracted from the analyses of recorded actions of the expert driver. By carefully analyzing the behavior, we were able to put together fuzzy rules and crucial parameters of the inference system.

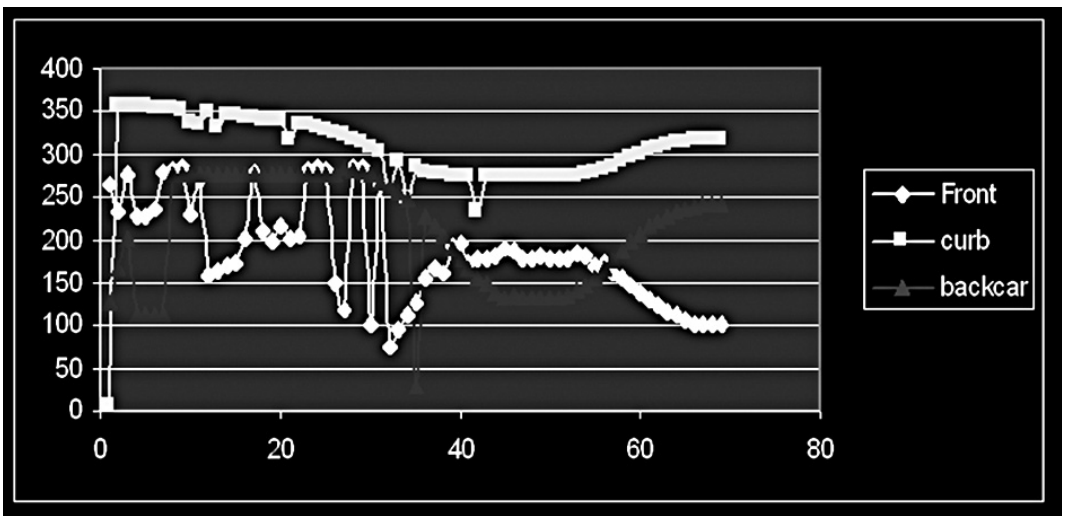

Figure 10. Recorded parameters as the expert driver executes a perfect parallel parking operation. The top number shows which image frame provided the parameters.

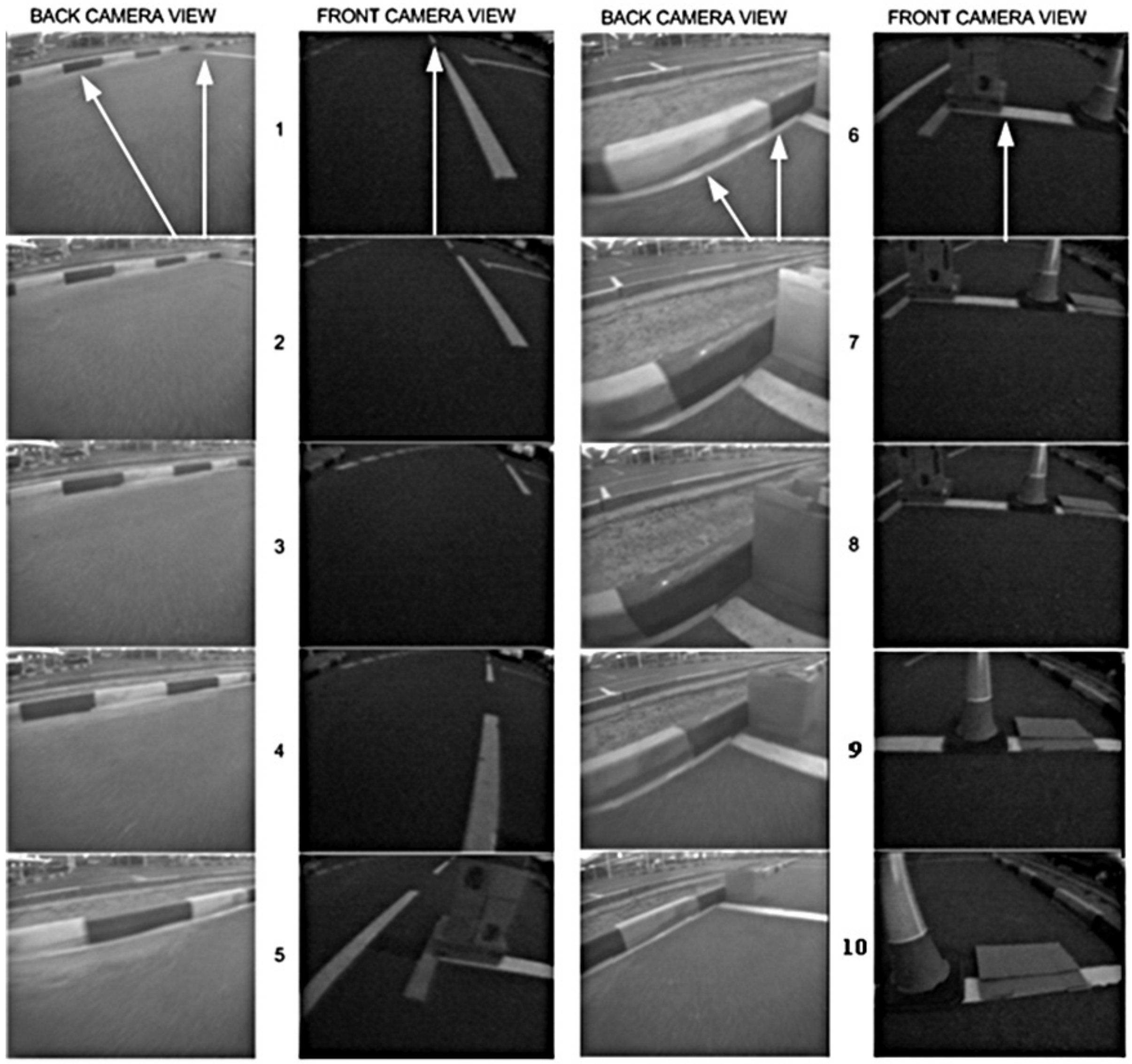

Figure 11. Actual recorded images which provided the parameters shown in Figure 10. Frames 1–8 are for Stage 1 and Frames 9, 10 are for Stage 2 operation.

3.5. HMI of the System

The system helps the driver to park his/her car using an HMI display screen placed on the dashboard of the vehicle. The screen layout has four quadrants for forward, backward movement and left and right steering. The suggested steering position and the movement, including the speed of movement, are shown on the screen as shown in Figure 12. Therefore, the driver can park the vehicle only by observing the screen without using mirrors. Parking aid system is implemented using a notebook computer, so in experiments we have placed the computer on the dashboard where notebook computer screen has also served HMI screen for driver guidance.

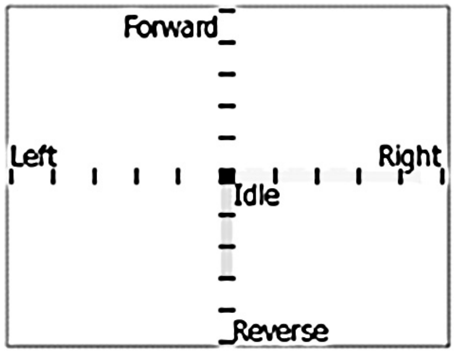

Figure 12. HMI interface of the parking aid guidance system instructing slow reverse movement with steering wheel turned almost fully in right direction.

4. Testing Robustness of the System

IEEE defines “Robustness” as the degree to which a system operates correctly in the presence of exceptional inputs or stressful environmental conditions. In order to test robustness we decided to test the system with different drivers under different conditions with different vehicles to see the quality of the parking.

Main functional feature requirements tested during the tests were as follows:

- F1: The system shall provide a direct real-time guidance to the driver about his/her car moving direction and the steering wheel.
- F2: The system should be able to operate in dry, cloudless and well lit environment.
- F3: The system should be operated with necessary hoods and filters to avoid glare.
- F4: The system should be able to operate in parking areas that have no painted lines in the street. The parking area shall be as black as the normal street color to avoid the corruptions and the noise detected in the images produced.
- F5: The lateral distance between the front car and the vehicle should be at least $1/2$ meter.
- F6: The system shall guide the user from the beginning of the parking position to the end, without bumping or crashing to the other two cars or the curb.
- F7: The system shall operate on “one go” to park the vehicle. So the driver shall stop next to the front car and switch on the system to prove 90% accurate guidance.
- F8: The system shall be smart enough to deal with novice user.
- F9: The system should guide the driver to adjust the speed of movement.
- F10: The output screen will indicate the user of how far the steering wheels should be turned.

Non-functional features to be tested:

- NF1: The system shall operate 90% failure free for 1 hour of continuous use.
- NF2: The System should be easy to upgrade in case it needs to be upgraded.
- NF3: The system should be easy to learn by the first time user and should have 97% accuracy of guidance.
- NF4: The system should be able to operate on any vehicle.
- NF5: The system shall be tested on left hand steering wheel system,
- NF6: The parking place shall be on the right side of the road.

The functional and non-functional requirements listed above are tested and the summary of some of the test cases are given in Table 1. Developed program, cameras and necessary software tools are loaded into a 1.4 GHz. Pentium 4 based notebook computer equipped with two USB cameras operating at 30 fps rate with 352×288 pixel resolutions. Tests are conducted with several different drivers, using two different vehicles and under different lighting conditions using different parking bays. The results of robustness tests are summarized in Table 1 below.

Test case no	Req’ment Tested	Comments	Result
1	F1	Operated with 0.4 second delay	PASS
2	F2	Automatic threshold adjustment to edge detection added	PASS
3	F3		PASS
4	F5	Passed with good result	PASS
5	F6		PASS
6	F7		PASS
7	F7	Different locations tested	PASS
8	NF3	First time user gets 80% quality parking	FAIL
9	NF4	Parameter needs to be adjusted for different vehicles	FAIL

Table 1. Summary of robustness testing results.

Some of the comments regarding tests are as follows:

Test case 1: The real time operation speed of the system is found to be quite satisfactory with 0.4-second update speed. The system evaluated current condition of vehicle and distances between obstacles continuously and provided new instructions to the driver every 0.4 seconds.

Test case 2: Although the initial functional requirements were for day light operation the system is found to be operational at night time if parking bay is sufficiently illuminated. During the course of the testing, automatic threshold adjustment to edge detection block is added which improved the parameter measurement process drastically.

Test case 5 and 7: The system is found operational in different parking locations and provided adequate distance between the parked vehicles.

Test case 8: First time user requirement has performed unsatisfactorily achieving only 80% quality of parking. Goal of quality parking was determined as having a lateral distance of 20 cm from the curb. First time users, although parked successfully, the lateral distance was found to be 25-30 cm.

Test case 9: When switching from one vehicle to another without any adjustment, the system failed. The fuzzy membership curves needed to be adjusted for the target vehicle, then the system performed satisfactorily.

5. Conclusion

A parallel parking guidance system based on biomimetic approach has been designed and tested. The goal of the project was to design a system mimicking behavior of an expert driver who operates without knowing details such as kinematics, dynamics of vehicle. The only information expert driver relies upon while performing parking maneuver are the visual cues he/she receives from around the vehicle. The behavior of the expert is recorded, analyzed and a fuzzy system mimicking his behavior is designed. The fuzzy rules are derived directly from the behavior of the driver.

Testing robustness of the system has revealed that system is successful in design goals with the exception of switching from a large vehicle to a small vehicle. The system is found operational with similar size vehicles, but switching to a much different size requires adjustment of membership curves.

The implemented system works by mimicking an expert driver, relying only on visual cues to park the vehicle. Although design and implementation of such a project were challenging, fuzzy logic and biomimicing approach worked surprisingly well. By recoding and studying actions of an expert, it was possible to decipher fuzzy rules of the action and use these rules for successful implementation of the system.

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