Automatic Parallel Parking

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Abstract
An automated parallel parking strategy for a vehicle-like robot is presented. This study addresses general cases of parallel parking within a rectangular space. The procedure consists of three phases. In scanning phase, Infrared sensors in the robot are used to scanning the parking environment in order to search a suitable parking position. Then maneuvering path is generated for different parking space in the next phase, starting phase. The robot moves backward to the edge of the parking space and starts its parking strategy. In maneuver tracking phase, the robot follows the maneuvering path to the parking position. It depends on the width of the rectangular space which has been scanned in the previous phase. This strategy has been implemented in a vehicle-like robot and is developed for an assistant to help human drivers in the future.

1. Introduction

An automated parallel parking strategy for a vehicle-like robot is presented. This study is part of the research project in the development of the autonomous vehicle control. Parallel parking is difficult for human driver especially for beginners. Therefore, this type of problems attracts a great deal of attention from the research community. This research is derived from the study of motion-planning of robots. There exists many algorithms in robot motion planning and they were difficult to apply those algorithms into four-wheels vehicle parking cases. The research on this topic can be classified into two groups: 1-stabilization of the vehicle to a point by means of feedback state; 2 - planning a feasible path to reach a point and following the path. In the former category, Yasunobu and Murai [1] have proposed a controller based on human experience to develop a hierarchical fuzzy control and predictive fuzzy control for vehicle parking. The vehicle is controlled moving point by point. That algorithm generates the maneuvering path point by point from the human knowledge base in the predictive fuzzy controller. Researchers not only concerning the classical four wheels vehicle, trailer vehicle are also considered. Jenkin and Yuhas [2] have reported a simplified neural network controller by decomposition. The neural controller is decomposed by subtasks. The neural controller is trained based on the kinematics data, however the decomposed neural network require less training time thus it has simplified the training process. Kinjo, Wang and Yamamoto [3] have used Genetic Algorithm (GA) to optimize neural controller for controlling trailer truck. Initially the neural controller is produced randomly and GA changes the weighting of the controller to a suitable value. The algorithms discussed above are based on the kinematics data to formulate intelligent controllers.

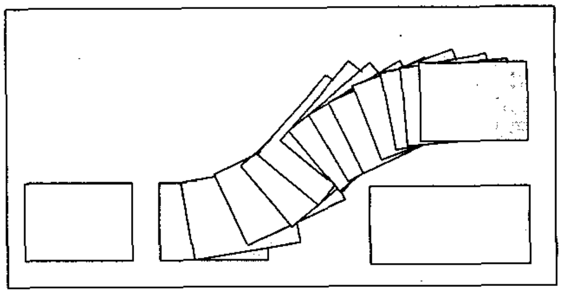

Figure 1 Maneuvering of Parallel Parking

For the path planning category, Paromtchik and Laugier [4] presented an approach to parallel parking for a nonholonomic vehicle. In that approach, a parking space is scanned before the vehicle moves backward into its parking bay. The vehicle follows a sinusoidal path in backward motion, while the forward motion is along a straight line without sideways displacement. In this approach, the possible collision during reverse between the vehicle and the longitudinal boundary of the parking space is not discussed. Murray and Sastry [5] worked on steering a nonholonomic system between arbitrary points by means of sinusoids.

Automatic parallel parking involves many problems, such as recognition of driving circumstances, maneuvering path planning, communication and vehicle control. This paper focuses on the maneuvering path planning. The system works in three phases. In scanning phases, the parking circumstance is scanned by infrared sensors after the parking command is activated. It then goes to next phase, starting phase, after a suitable parking space has been detected. The maneuvering path is also produced according to the scanned information. The robots moves backward to the edge of the parking position and begins its parking strategy. In order to avoid potential collision, the robot starts at the suitable position which depends on different dimension of parking space. In the final phase, maneuver tracking phase, the robot follows the path to a desired parking position. The parameters of the maneuvering path have been produced off-line. A database has been built for different circumstance such as the longitudinal and lateral dimension of parking space, the dimension of vehicle-like robot, its specification of the steering angle (maximum turning angle) and lateral displacement from the aside car.

2. Car Modelling

A four-wheeled vehicle-like robot is considered. The location of the vehicle reference to the coordinate system is denoted as (x, y, θ), where x, y are the coordinates of the midpoint of the robot's back wheel axis and θ is the orientation of vehicle that the angle relative to its parallel position. Therefore, the motion of vehicle in time-varying can be described as the followings:

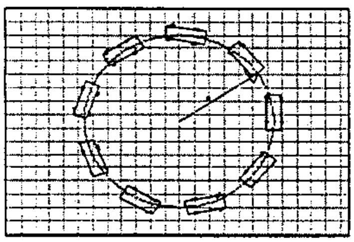

Figure 2 Radius of locus

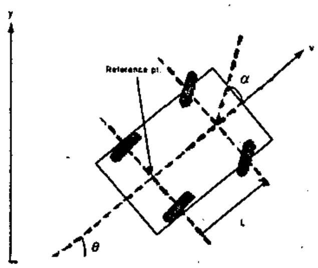

Figure 3 Vehicle model

$$\frac{dx}{dt} = v\cos\alpha\cos\theta$$
$$\frac{dy}{dt} = v\cos\alpha\sin\theta \qquad (1)$$
$$\frac{d\theta}{dt} = \frac{v\sin\alpha}{L}$$

where α is the steering angle, v is the velocity of the vehicle and L is distance between two wheel axis. Equations (1) are valid for the robot moves in flat ground in slow speed and there is no significant slippage. In planar motions, the robot subject to a constraint which is the limits of the steering angle α, $-\alpha_{max} < \alpha < \alpha_{max}$. The control parameters in the car model are longitudinal velocity and steering angle (v, α) but there are three degree of freedom (x, y, θ) [6]. When the speed of the robot is constant and its steering angle is fixed, the planar motion is approximately a circle see figure 2. The radius of the locus depends on its steering angle. Thus, the steering angle constraint implies another constraint which is minimum radius of the circular movement. This radius limits longitudinal distance of the parking space. Therefore, it specifies the minimum space for parking which is required in the scanning phase. In our maneuvering planning, the vehicle moves in the shortest path and with single iteration move into the parking bay. The characteristic of vehicle kinematics helps to design the simple parking path.

3. Maneuvering Planning

The parallel parking idea of this paper described is coming from retrieving a vehicle from parallel parking bay. In real life situation, when the parking bay is sufficiently large, human driver normally will steer the front wheel to max angle for retrieving. When the vehicle is retrieved, the driver will steer the front wheel in reverse direction until the car is parallel to the road. Since this procedure is reversible thus it can be applied in parallel parking problem. Furthermore, this procedure is simplified the steering angles to the minimum radius condition. Effectively, according to the vehicle steering scenario described at the former section two identical circles with tangent point can be formed. For example, a vehicle moves backward from A to B following a path formed by two circular arcs tangentially connected to each other. Supposing B is parking bay and A is starting position, thereby parallel parking is achieved (see figure 4). The locations of circle center are

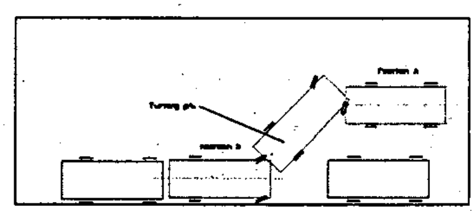

Figure 4 Reference point of vehicle

depending on the detected parking space and the lateral displacement from the aside car.

There are several conditions have to fulfill in order to have a collision-free motion (see figure 5):

1. The length L must be larger than radius of the circle C_1.
2. The car must at a correct position when begin to parking. The right position is determined by Δx and Δy.
3. The tuning point ΔT is depending on different value of Δx and Δy.

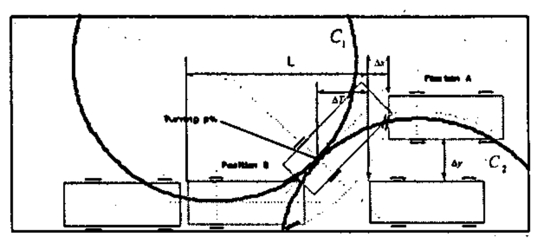

Figure 5 Maneuvering parameters

In our methodology the vehicle is always track to the tangential circles. Thereby, the location of circles must be determined. When the parking position is decided, which depends on the length of parking space, the center of C_1 is vertically perpendicular to the final parking position. Thus the remaining problem is the location of the centre of $C_2(C_x, C_y)$. However, the center of C_2 is varied with the lateral distance between the aside car (Δy). Figure 6 shows the geometric representation of the parameters required for calculation.

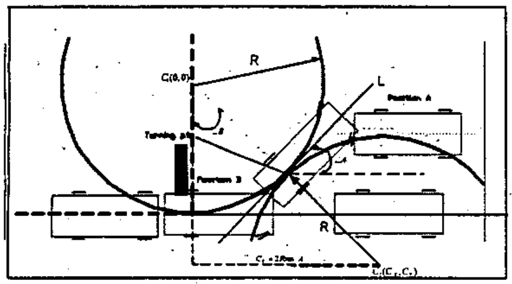

Figure 6 Geometry representation of maneuvering calculation

Calculating $C_2(C_x, C_y)$ and the turning (x_t, y_t) the following equations are used

$$C_2 : (x - C_x)^2 + (y - C_y)^2 = R^2$$

$$C_1 : x^2 + y^2 = R^2$$

$$\frac{dy}{dx} = \frac{x}{\sqrt{R^2 - x^2}}$$

at the turning point (x_t, y_t),

$$\frac{\Delta y}{\Delta x} = \frac{x_t}{\sqrt{R^2 - x_t}} \quad \ldots\ldots\ldots\ldots(2)$$

For the line equation L: $\frac{x - x_t}{y - y_t} = m \quad \ldots\ldots\ldots\ldots(3)$

Substitute y=0 into (2) to find x_1, then

$$\angle A = \tan^{-1}\left(\frac{y_t}{x_t - x_1}\right)$$

$$C_x = 2R\sin A$$

$$C_y = -2R\cos A$$

In order to reduce the load of MCU off-line calculation of parameters are implemented. Since the parking procedure is a reverse process of retrieving procedure. Therefore the parking parameters can be obtained by simulating the retrieving process. A simulation is written to emulate the retrieving process. In the simulation, the length of the parking space can be set. Since the center of the first circle is fixed that is perpendicular to the starting position of the vehicle (in the retrieving process i.e. the final position in parking process), thus the vehicle follows the path to move. Then different turning points are assigned to the vehicle in the simulation and it is a tangential point between two circles. Therefore, two centers of the circles are then known and different value of turning point evaluate different circle's centre. Several of circular loci are generated. By measuring final positions (in the retrieving process. i.e. the starting position in parking process) on different loci (i.e. different turning point) Δx and Δy are determined. As a result, a table of relationship between turning point (x_t, y_t), Δx and Δy on specific length of parking space are stored. In order to realize the parking algorithm in the robot a series of parking length are emulated and the result are being used in the evaluation of MCU.

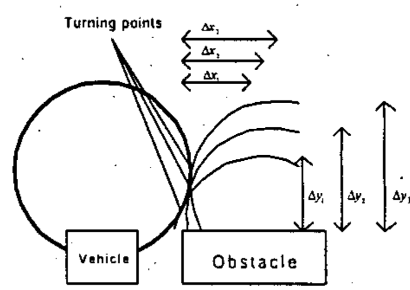

Figure 7 Retrieving Loci at different turning point

The system works in three phases (see figure 8) :

1. In scanning phase, the vehicle-like robot scans parking environment by infrared sensor in order to detect the lateral and longitudinal length of the parking space. Obstacle inside the parking bay can also be detected in this phase. Therefore, potential collision in the parking maneuvering can be avoided from this scanning phase. Those data are used for selection of suitable parking bay (see figure x). Information of bay's dimension and distance between aside car Δy are measured in this phase.
2. In starting phase, the robot moves backward to adjust suitable Δx in order to start collision-free motion. These parameters are found from look-up table based on parking bay's dimension and Δy which is built by off-line simulation. The detail is described from previous section.
3. In maneuvering phase, the steering angle is turned to maximum right and the robot moves backward with constant speed. It tracks the locus by steps counting in the servo system. It then turned into maximum left at the predefined turning point, and eventually stop when the robot become parallel to the lane.

4. Experimental Studies

A car-like robot has been developed with 1/10th scaled model car framework is used for our experiments. This is a four-wheeled robot with front-driven and steering wheels. It has the following dimension: 20cm (L) x 48cm (W). It is equipped with low speed DC motor and its steering system is controlled by servo motor for front-driven. The range measurement system consists of two Infrared Distance Measure Sensors (GP2D12). The control system is based on micro-controller AT89c51.
The objective of experiment is testing the effectiveness of parallel parking algorithm and maneuvering planning strategy.

There are two obstacle located at the right hand side of the vehicle to mimic the real parking situation. The robot should able to find the parking position and finally maneuver into the space between two blocks without collision.

According to figures 10.1 to 10.2, the car was measuring the depth and the length of the parking space. When the vehicle began to its parking process (figure 10.3), its position Δx was adjusted by value of Δy . The front wheel was steered into maximum right and moved backwards to follow a circular locus (figure 10.4). It then turned to maximum left after it had reached the turning point. Finally, it was stopped when the car was parallel to the road.

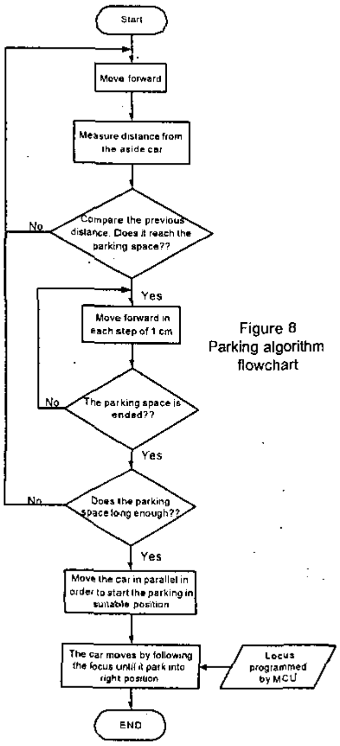

Figure 8
Parking algorithm
flowchart

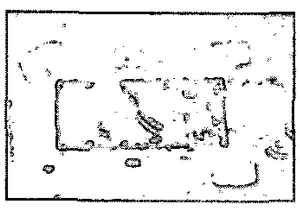

Figure 9 Prototype of car-like robot

5. Conclusion

We have introduced an interesting idea on automatic parallel parking by a simplified approach that can be implemented into a single-chip MCU. This idea was successfully tested on the autonomous vehicle. Nevertheless, there are two assumptions such as frictional force between the wheel and the road is reasonably high that slip can be neglected. Also, the surroundings circumstance has no changes during parking. For future development, more sensors should be installed, especially sensors at the back of the vehicle, to become more *adaptive to the changing environment.*

6. Reference

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