Automatic Parallel Parking and Returning to Traffic Maneuvers

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Abstract

This video illustrates a control approach developed to perform parallel parking and returning to traffic maneuvers for a car capable of autonomous motion. The key idea is to carry out a motion control procedure involving a "Localization-Planning-Execution" cycle until a specified location of the car relative to its environment is reached. Range measurements are used to model environmental objects around the car. The automatic maneuvers developed are demonstrated on an experimental electric autonomous car in a usual traffic environment.

1 Introduction

Many drivers have difficulties or make errors while parallel parking or in pulling out of a parking place. A control approach to automatic parallel parking and pulling out maneuvers has been developed and tested on an experimental electric car capable of autonomous motion. The manual car driving is supplemented with an automatic steering and velocity control [1]. The car is equiped with: (1) - a sensor unit to measure relative distances between the car and environmental objects, (2) - a servo unit for low-level control of the steering angle and locomotion velocity, (3) - a control unit that processes data from the sensor and servo units and "drives" the car by issuing appropriate servo commands. The sensor unit uses range sensors to measure relative distances between the car and environmental objects. The servo unit consists of a steering wheel servo-system, a locomotion servo-system for forward and backward motions, and a brake servo-system to slow down and stop the car. The microcomputer-based control unit monitors the current steering angle, locomotion velocity, travelled distance, coordinates of the car and range data from the environment, calculates an appropriate local trajectory and issues the required servo commands.

A kinematic model of the car is used to describe its motion during parking and pulling out maneuvers. The coordinates of the car are denoted as $(x,\, y,\, \theta)$ relative to some reference coordinate system where $x = x(t)$ and $y = y(t)$ are the coordinates of the midpoint of the rear wheel axle, $\theta = \theta(t)$ is the orientation of the car, and t is time. The motion of the car is described by the equations

$$\begin{cases} \dot{x} = v\, \cos\phi\, \cos\theta, \\ \dot{y} = v\, \cos\phi\, \sin\theta, \\ \dot{\theta} = \frac{v}{L}\, \sin\phi, \end{cases} \qquad (1)$$

where $\phi = \phi(t)$ is the steering angle, $v = v(t)$ is the locomotion velocity of the midpoint of the front wheel axle, and L is the wheel base. The steering angle and locomotion velocity are two control commands $(\phi,\, v)$. Equations (1) correspond to a system with nonholonomic constraints because they involve the derivatives of the coordinates of the car and are non-integrable [2]. Equations (1) are valid for a four wheel vehicle moving on flat ground with a pure rolling contact without slippage between the wheels and the ground.

2 Summary of the approach

Automatic parallel car parking involves a controlled sequence of motions, in order to localize a sufficient parking place along the road side, obtain a convenient start location for the car beside the parking place, and perform a parallel parking maneuver [3, 4, 5]. For localization of a parking place, the car moves slowly along the traffic lane. Range data is used to build a local map of the environment alongside the car. An available parking place is detected, its dimensions are compared with those of the car and a decision on suitability for parking is made. A convenient start location for a backward motion of the car into the parking place is computed, and the car reaches this location.

Feasible controls (steering angle and locomotion velocity) that correspond to a nominal motion leading to the "parked" location are planned and executed in real time. The following control commands provide the parallel parking maneuver [3, 4]:

$$\phi(t) = \phi_{max}\, k_\phi\, A(t), \quad 0 \,\le\, t \,\le\, T, \qquad (2)$$

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$$v(t) = v_{max}\, k_v\, B(t), \quad 0 \le t \le T, \qquad (3)$$

where $\phi_{max} > 0$ and $v_{max} > 0$ are the admissible magnitudes of the steering angle and locomotion velocity respectively, $k_\phi = \pm 1$ corresponds to a right side (+1) or left side (–1) parking place relative to the traffic lane, $k_v = \pm 1$ corresponds to forward (+1) or backward (–1) motion,

$$A(t) = \begin{cases} 1, & 0 \le t < t', \\ \cos \frac{\pi(t-t')}{T^*}, & t' \le t \le T - t', \\ -1, & T - t' < t \le T, \end{cases} \qquad (4)$$

$$B(t) = 0.5 \left(1 - \cos \frac{4\pi t}{T}\right), \quad 0 \le t \le T, \qquad (5)$$

where $t' = \frac{T-T^*}{2}$, $T^* < T$, and T is duration of the motion. In this way, the form of the control commands (2) and (3) for the parallel parking maneuver is defined by (4) and (5) respectively. In order to evaluate (2)-(5), the durations T^* and T, the magnitudes ϕ_{max} and v_{max} must be known.

The value of T^* is lower-bounded by the kinematic and dynamic constraints of the steering wheel servo-system. When the control command (2), (4) is applied, the lower bound of T^* is

$$T^*_{min} = \pi\, \mathbf{max} \left\{ \frac{\phi_{max}}{\dot{\phi}_{max}},\ \sqrt{\frac{\phi_{max}}{\ddot{\phi}_{max}}} \right\}, \qquad (6)$$

where $\dot{\phi}_{max}$ and $\ddot{\phi}_{max}$ are the maximal admissible steering rate and acceleration respectively for the steering wheel servo-system. The value of T^*_{min} gives duration of the full turn of the steering wheels from $-\phi_{max}$ to ϕ_{max} or vice versa, i.e. one can choose $T^* = T^*_{min}$.

The value of T is lower-bounded by the constraints on the velocity v_{max} and acceleration $\dot{v}_{max}$ and by the condition $T^* < T$. When the control command (3), (5) is applied, the lower bound of T is

$$T_{min} = \mathbf{max} \left\{ \frac{2\pi\, v'(D_l)}{\dot{v}_{max}},\ T^* \right\}, \qquad (7)$$

where the empirically-obtained function $v'(D_l) \le v_{max}$ serves to provide a smooth motion when the available distance D_l for the longitudinal displacement within the parking place is small.

The computation of T and ϕ_{max} aims to obtain the maximal values that assures the maximal longitudinal and, especially, lateral displacement of the car within the available space of the parking place. The computation is carried out on the basis of the model (1) when the commands (2) and (3) are applied. In this computation, the value of v_{max} must correspond to a safety requirement for parking maneuvers (e.g. $v_{max} = 0.75\ m/s$ was found empirically).

Once the motion is carried out, the sensor data is used to decide whether the "parked" location with respect to environmental objects has been attained. If not, forward and backward motions with the coordinated control of the steering angle and locomotion velocity are iteratively performed to produce a required lateral displacement of the car into the parking place.

For each pair of successive motions $(i,\, i+1)$, the coefficient k_v has to satisfy the equation $k_{v,i+1} = -k_{v,i}$ that alternates between forward and backward directions. Between successive motions, when the velocity is null, the steering wheels turn to the opposite side in order to obtain a suitable steering angle ϕ_{max} or $-\phi_{max}$ to start the next iterative motion. After the required lateral displacement into the parking place has been completed, the car adjusts its location to midway between the front and rear vehicles to ensure a proper distance.

Automatic pulling out of the parking place involves: localizing an available space for the car motion within the parking place, placing the car at a convenient location at the rear border of the parking place, and performing a maneuver to pull the car away from the parking place into the traffic lane. Range data is used for localization of an available space within the parking place. Similar to the parking maneuver, the control commands (2) and (3) with

$$A(t) = k_v, \quad 0 \le t \le T, \qquad (8)$$

$$B(t) = 0.5 \left(1 - \cos \frac{2\pi t}{T}\right), \quad 0 \le t \le T \qquad (9)$$

are planned, and the duration T, the magnitudes ϕ_{max} and v_{max} are obtained. In this way, the form of the control commands (2) and (3) is defined by (8) and (9) respectively.

Initially, a backward motion is performed to place the car close to the rear border of the parking place and reorient the car in an outward direction. Once this motion is carried out, the sensor data is used to decide if a collision-free motion to leave the parking place is possible. If not, forward and backward motions are performed until an orientation that permits a collision-free motion is obtained. To alternate between forward and backward directions, the coefficient k_v satisfies the equation $k_{v,i+1} = -k_{v,i}$ for each pair of successive motions $(i,\, i+1)$. Between successive motions, when the velocity is null, the steering wheels turn to the opposite side in order to obtain a suitable steering angle ϕ_{max} or $-\phi_{max}$ for the next iterative motion. When the collision-free motion to leave the parking place is possible, feasible control commands $(\phi,\, v)$ that correspond to a nominal motion leading into the traffic lane are planned. The car moves forwards away from the parking place into the traffic lane. Finally, the car stops in the traffic lane and is then ready for further manual driving.

3 Experiments

The method developed has been tested on an experimental automatic car designed on the base of a LIGIER electric car, shown in Fig. 1. The vehicle can either be manually driven as a car, or it can move autonomously. To allow autonomous motions, the car is equiped with a control unit based on a Motorola VME162-CPU board and a transputer net. The sensor unit of the car consists of ultrasonic range sensors (Polaroid 9000) and a linear CCD-camera. The steering wheel servo-system is equiped with a direct current motor and an optical encoder to measure the steering angle. The locomotion servo-system of the vehicle is equiped with 12 kW asynchronous motor and two optical encoders at the rear wheels to provide data on locomotion velocity. The car also has an hydraulic braking servo-system. The developed steering and velocity control is implemented using ORCCAD software [6] running on a SUN workstation. The compiled code is transmitted via Ethernet to the VME162-CPU board.

Figure 1: a LIGIER electric car

The developed parallel parking and pulling out maneuvers have been tested in a usual traffic environment within a parking area, as depicted in Fig. 2 where a traffic lane is denoted as C1, and parking lanes are denoted as C2 and C3. In this Figure, A1 is an automatic car moving in a direction shown by an arrow F1 along the traffic lane C1, B1 - B6 are parked cars, P1 - P4 are available parking places, C4 and C5 indicate the right and left road curbs respectively.

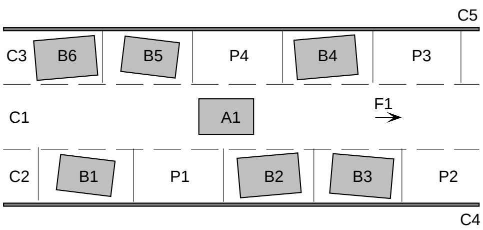
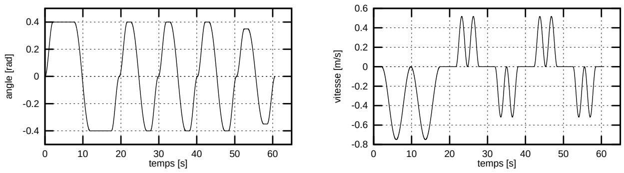


Figure 2: parking situations along road sides

An example of the control commands (2) and (3) for the parallel parking maneuver is shown in Fig. 3, and the corresponding maneuver is plotted in Fig. 4 where the parking place is between two cars parked in the left side parking lane. The obtained $(x,\, y)$-path of the midpoint of the rear wheel axle of the car consists of S-shaped curves required for the parallel parking maneuver.



a b

Figure 3: an example of the control commands for the parallel parking maneuver: a - steering angle, b - locomotion velocity

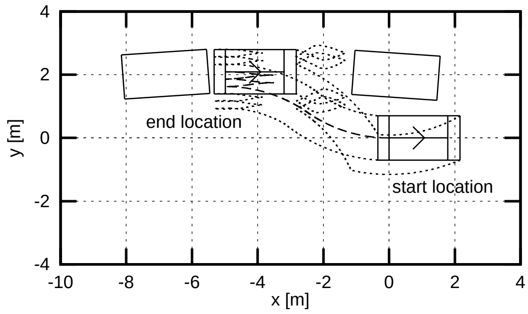


Figure 4: an example of the parallel parking maneuver

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