AUTONOMOUS PARKING USING A SENSOR BASED APPROACH

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INTRODUCTION
Parking and unparking are often difficult tasks, especially for unexperienced drivers. They involve:

- Finding a suitable parking spot
- Maneuver either into or from the (often tight) parking spot without colliding with anything while trying to avoid disturbing the surrounding traffic.

All of this hassle could be avoided with an *Autonomous Parking* system
The different control approaches available in the literature can be divided into two categories:

- Based on stabilizing the vehicle to a target point
- Based on path planning.

Typically, highly dependent on the localization performance.

⇒ Sensor based control, an interesting possibility.
MODELING AND CONTROL
Car-Like Robot Rear-Wheel Driving

Figure: Kinematic model diagram for a car-like rear-wheel driving robot

\[
\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{\theta} \\
\dot{\phi}
\end{bmatrix} =
\begin{bmatrix}
\cos \theta \\
\sin \theta \\
\tan \phi/l_{wb} \\
0
\end{bmatrix}
\begin{bmatrix}
v \\
0 \\
0 \\
1
\end{bmatrix}
\]

Where \(v\) and \(\dot{\phi}\) are the driving and steering velocities.

The relation between \(\phi\) and \(\dot{\theta}\) can be expressed as:

\[
\phi = \text{atan}\left(\frac{\dot{\theta} l_{wb}}{v}\right)
\]
Experimental Setup

Velocity, direction of travel, steering and turning signals can be controlled by computer.

Figure: HDK DEL2030DUB
Sensor Based Control With A Weighted Control Scheme

\[ \dot{s}_i = L_i v_i \]

\[ v_i = i W_m v_m \]

\[ i W_m = \begin{bmatrix} i R_m & [i t_m] \times i R_m \\ 0_{3x3} & i R_m \end{bmatrix} \]

\[ L_S = L W_m = \begin{bmatrix} L_1 & \ldots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \ldots & L_k \end{bmatrix} \begin{bmatrix} 1 \ W_m \\ \vdots \\ k \ W_m \end{bmatrix} \]

\[ \dot{s} = L_S v_m \]

---

In the current implementation, the sensor measurements are already on $F_m$, leading to:

$$\dot{s}_i = L_i v_i = L_i v_m$$

$$\dot{s} = L_s v_m$$

$$L_s = \begin{bmatrix} L_1 \\ \vdots \\ L_k \end{bmatrix}$$

$$v_m = -\lambda C e$$

$$C = (H \hat{L}_s)^+ H$$
Sensor Based Control - Weighted Error

\[ e_H = H e \]
\[ e = s - s^* \]
\[ H = \text{diag}(h_1, \ldots, h_d) \]
\[
H = \begin{bmatrix}
H_1 & \ldots & 0 \\
\vdots & \ddots & \vdots \\
0 & \ldots & H_k
\end{bmatrix}
\]
\[ \forall i \in [1, d] : h_i = h_i^t + h_i^c \]

\[ h_i^c = \begin{cases}
\frac{s_i^{s-} - s_i}{s_i - s_i^c} & \text{if } s_i < s_i^{s-} \\
0 & \text{otherwise}
\end{cases} \]

Figure: Weighting \( h^c \) for the basic constraint
Perception
PointCloud Processing

- PointCloud filtering and downsampling
- Extract required data from bounding boxes characteristics
- Segmentation
- Find bounding boxes for the detected obstacles (clusters)
- Clustering
Extraction of empty parking place

Spot Depth

Spot Length

\[ c_{13} \quad c_{12} \quad c_{23} \quad c_{22} \]

\[ l_s \]

\[ d_1 / 2 \]

\[ c_{14} \quad c_{11} \quad c_{24} \quad c_{21} \]

\[ d_2 / 2 \]

\[ d_1 \]

\[ d_2 \]
The control sensor feature $s_1$ is extracted from the closest side (of the two largest sides) of $obs_1$ to the vehicle. The point $(x_1, y_1)$ is chosen to be always the one further to the back of the vehicle.

$$s_1 = [x_1, y_1, \beta]^T$$

$$L_{s_1} = \begin{bmatrix} -1 & y_1 \\ 0 & -x_1 \\ 0 & 1 \end{bmatrix}$$

$$L_i = \frac{L_{s_i} + L^*_s}{2}$$
The constraints sensor features $s_2$ and $s_3$ correspond to, respectively, the closest distance between either the left or right side of the vehicle and $obs_1$ or $obs_2$.

$$\forall j \in [1, 2]: s_{1+j} = distToObs_j = \sqrt{x_{obs_j}^2 + y_{obs_j}^2}$$

$$L_{s_{1+j}} = \begin{bmatrix} -\frac{x_{obs_j}}{distToObs_j} & 0 \\ L_{s_i} + L_{s_i}^* \end{bmatrix}$$

$$L_i = \frac{L_{s_i} + L_{s_i}^*}{2}$$
Results
Figure: Extraction of empty parking place using offline data (speed: 2x)
Figure: Results of the implementation of a state-of-the-art path planning approach\(^2\) (speed: 1.75x)

Simulation Results - Path Planning Approach

**Perpendicular parking maneuver**

![Perpendicular parking maneuver graph](image1)

- Path performed
- Circular reference

**Evolution of the state variables**

![Evolution of the state variables graph](image2)

- x (m)
- y (m)
- theta (degs)

Figure: Path performed by the vehicle and the reference circle that connects positions 1 and 2

Figure: Evolution of the state variables over time

Final error values: \( x = -37.7 \text{ mm}, \ y = -2.6 \text{ mm}, \ \theta = 0.000 \, 08^\circ. \)
Simulation Results - Path Planning Approach

**Linear velocity evolution**

- Reference
- Actual

**Steering angle evolution**

- Reference
- Actual

Figure: Evolution of the vehicle’s linear velocity - path planning

Figure: Evolution of the vehicle’s steering angle
Figure: Results using the proposed sensor based approach - reverse maneuver (speed: 1.75x)
Simulation Results - Sensor Based Approach

Figure: Evolution of the error signal - reverse maneuver

Figure: Evolution of the constraints - reverse maneuver

Final error values: $x_1 = -6.5 \text{ mm}, \ y_1 = 7.2 \text{ mm}, \ \beta = 0.0102^\circ$. 
Simulation Results - Sensor Based Approach

Linear velocity evolution

Steering angle evolution

Figure: Evolution of the linear velocity - reverse maneuver

Figure: Evolution of the steering angle - reverse maneuver
Simulation Results - Sensor Based Approach

Figure: Results using the proposed sensor based approach - forward maneuver (speed: 1.75x)
Simulation Results - Sensor Based Approach

Figure: Evolution of the error signal - forward maneuver

Figure: Evolution of the constraints - forward maneuver

Final error values: $x_1 = 20.9$ mm, $y_1 = 0.7$ mm, $\beta = -0.0019^\circ$. 
Simulation Results - Sensor Based Approach

**Linear velocity evolution**

- Time: 0 to 30 seconds
- Linear velocity (km/h): 0 to 2.5

**Steering angle evolution**

- Time: 0 to 30 seconds
- Steering angle (degs): -30 to 20

Figure: Evolution of the linear velocity - forward maneuver

Figure: Evolution of the steering angle - forward maneuver
Real Experimentation Results - Sensor Based Approach

Figure: Preliminary results with the real vehicle using the proposed sensor based approach
Real Experimentation Results - Sensor Based Approach

**s1 - s1**

![Graph of s1 - s1*](image1)

**Constraints**

![Graph of constraints](image2)

Figure: Evolution of the error signal

Figure: Evolution of the constraints

**Final error values:**

\[ x_1 = -10.4 \text{ cm}, \ y_1 = 11.9 \text{ cm}, \ \beta = -0.0637^\circ. \]
Real Experimentation Results - Sensor Based Approach

- Linear velocity evolution
- Steering angle evolution

Figure: Evolution of the linear velocity
Figure: Evolution of the steering angle
Conclusions
Conclusions

- Under simulation, the proposed sensor based approach is able to achieve slightly smaller errors in position than the path planning approach.
- The proposed approach is very versatile, requiring only some minor modifications to change between reverse and forward maneuvers.
- The proposed approach has been proved to be a valid one considering the results obtained from simulation and real experimentation.
- More work has to be done to improve the performance when using the real vehicle.
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