SAE TECHNICAL PAPER SERIES

2006-01-0810

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Reprinted From: Intelligent Vehicles & Transportation Systems (SP-2027)

ISBN 0-7680-1633-9

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2006 SAE World Congress
Detroit, Michigan
April 3-6, 2006

SAE International™

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The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

ISSN 0148-7191

Printed in USA

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ABSTRACT

This paper describes a system for supporting the driver of a passenger car in different parking situations. Todays cars are getting larger in size and the drivers view in both forward and rearward direction is becoming more limited. This fact calls for a system of sensors and algorithms capable of supporting the driver through the parking maneuvre in a safe and smooth way.

The paper presents the development of some of the subsystems in a fully automatic parallel parking system, utilizing ultrasonic ranging sensors for environment mapping. In contrast to existing passive parking aid systems, the ultrasonic range sensors need to have a narrower aperture to be able to map the surroundings properly. This can be accomplished by either increased sensor size or by a higher number of sensors.

The emphasis of the paper is the signal conditioning in the parking system. The Hough-transform along with a statistical CUSUM test are used to find the properties of the target parking space.

The system makes use of hardware components already available in modern cars and a small number of added components. The resulting system is automated, from finding a suitable parking space to maneuvering the car into the parking space, while keeping the driver in authority since the longitudinal control, i.e. throttle and brakes, are still the drivers responsibilities.

The prototype system is implemented in a Volvo S60 which has been modified with an electric power steering unit and an ultrasonic sensor array consisting of a total of six sensors spread out around the vehicle. The electric power steering unit is used for steering wheel angle control when the system is active by adding an external torque to the assist torque normally applied.

Figure 1: The prototype car used for the automatic parking system

INTRODUCTION

The automatic parking system used in this paper is installed in the prototype car seen in Figure 1. The system uses ultrasonic sensors to create a map of the target parking space.

A parking space is considered valid by the system if it is confined by obstacles, such as other parked vehicles. It must also be large enough and have a rectangular or almost rectangular shape. The task of finding valid parking spaces from a number of sensor readings can therefore be reduced to finding straight lines among the readings.

Since the ultrasonic sensors are subject to a large number of spurioses due to reflection [6] it is important that the information extracting algorithm is robust against these. In

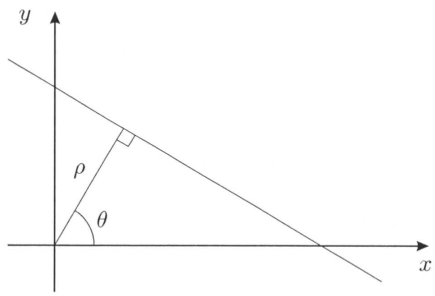

Figure 2: Illustration of the normal parameters for a line in the $x - y$ plane

[4] it is stated that the Hough Transform is more efficient on range data, such as for example ultrasonic data, than it is on images. The algorithm performs better on a smaller set of high quality data than on huge sets of image points.

All this makes the Hough Transformation [2] a strong candidate for information extraction in this application.

THE HOUGH TRANSFORM

The Hough transformations main usage is in image processing. The theory behind it is to transform each of the interesting picture points to a parameter space, where the parameters are chosen to describe lines or other shapes in the picture plane.

The so called *normal parameterization* is used here. This parameterization defines a straight line by the angle θ of its normal and the algebraic distance ρ from the origin, see Figure 2. Such that for the i:th picture point:

$$\rho_i = x_i \cos\theta + y_i \sin\theta \qquad \theta \in [0, \pi] \tag{1}$$

This parametrization is done for all picture points and stored in a quantized accumulator, $C(d, \theta)$ with $d = 2n\delta_\rho$, $n = 0, \pm1, \pm2, \pm3, \ldots$ where the quantization δ_ρ is a measure of the acceptable error.

$$C(d, \theta) = \sum_i w\left(\rho_i - d\right) \tag{2}$$

With ρ_i according to Equation 1 over i picture points and w is the unit rectangular window such that

$$w(x) = \begin{cases} 1 & |x| \leq \delta_\rho \\ 0 & |x| > \delta_\rho \end{cases} \tag{3}$$

In this parameterization any line in the picture plane ($x - y$) corresponds to a point in the parameter plane ($\theta - \rho$). Additionally every point in the $x - y$ plane corresponds to a sinusoidal curve in the $\theta - \rho$ plane.

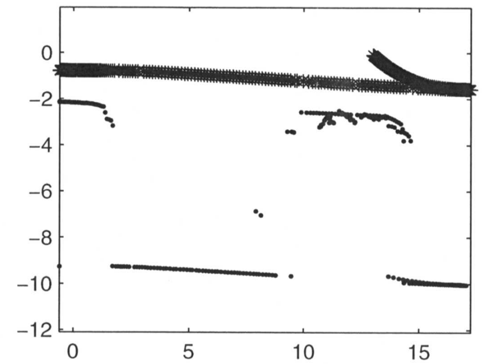

Figure 3: Actual sensor data with two parked cars and no curb, the sensor is mounted perpendicular to the right side of the car (crosses in the top of the figure, the measured objects are the dots in the lower part of the figure)

AN EXAMPLE

For this example data was collected from the prototype car by driving it past two other parked cars. There was no curb present for this run so echoes between the cars are set at the maximum sensing distance, which is approximately 9 meters. This distance is hereafter referred to as the *sonar horizon*.

The data for this run can be seen in Figure 3. The car was driven past the parking space from left to right in the figure and then reversed along the curve in the far right part of the figure. The large dots in the upper part of the figure represent the position of *the sensor* at each reading, the smaller dots below are the calculated echo position.

Although the prototype car is equipped with six ultrasonic sensors, only the one facing perpendicular to the right side of the car is required when using the algorithms in this paper.

With data from this run the Hough Transform should be able to detect two of the lines confining the parking space. One at the outer edge of the the two parked cars (a line at approx. -2 in Figure 3) and the other at the sonar horizon (a line at approx. -9 in Figure 3). If a curb was present the two lines would instead be the curb and the outer edge of the parked cars.

The other two lines, namely the front of the car behind the parking space and the rear of the car in front, can be found from the same sensor data with the use of statistical change detection. For example by making a CUSUM test [5] of the data.

A FIRST APPROACH

The first approach is to parameterize the data straight away using equation 1 which yields the parameter space shown in Figure 4. Higher peaks represent a stronger line, i.e. a higher count of points on a line in the picture

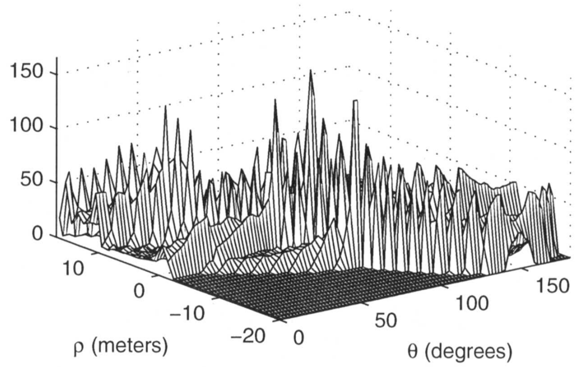

Figure 4: Straight forward parameterization of the data in Figure 3

plane. The angular resolution of the quantized accumulator $C(d, \theta)$ was set at $2°$ and the radial resolution to $\delta_\rho = 0.5$m.

Although three peaks in Figure 4 are clearly higher than the others, the noise is rather high.

The cause for the high noise lies in how the car is maneuvred during the operation. The car will be at a standstill in different phases of the parking space search and at these positions the sensor will measure the same object many times which really does not add any information and distorts the information in the discretizised accumulator $C(d, \theta)$.

THE SECOND APPROACH

To remedy the high noise a new approach where each sensor reading is weighted with the current car velocity, which effectively removes the disturbance echoes discussed above. A similar approach is taken in the range-weighted Hough Transform (RWHT, see [3, 4]), where the weight function is proportional to the distance.

The range weighted Hough transform can be written as:

$$C_g(d, \theta) = \sum_i w(\rho_i - d)\, g \tag{4}$$

where g is the weighting function.

In this application a filtering of all measurements taken when the vehicle is stationary is sufficient to elevate the strength of the wanted lines above the noise. The weight function is chosen as a rectangular window function such that:

$$g(v) = \begin{cases} 1 & v \geq v_{tresh} \\ 0 & v < v_{tresh} \end{cases} \tag{5}$$

Where the threshold speed v_{tresh} is tuned for best performance, in this example it is set to 0.4 m/s.

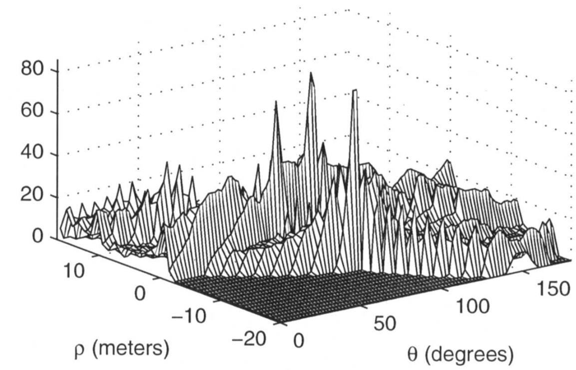

Figure 5: Weighted parameterization of the data in Figure 3, note that the noise is significantly lower than the unweighted version in Figure 4

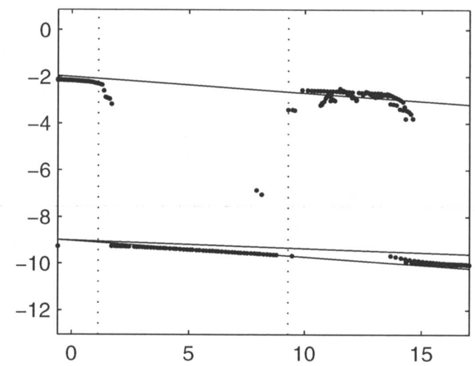

Figure 6: Retransformation of the three strongest lines from Figure 5 shown in Table 1, the dotted lines are the result from a CUSUM test made on the raw data

With this approach, three distinct lines (significantly higher peaks) can easily be seen in Figure 5. The lines are tabulated in Table 1.

Table 1: The three strongest lines.

θ	ρ	$C_g(d, \theta)$
$86°$	-9	85
$86°$	-2	86
$88°$	-9	85

A retransformation of the three strongest lines from Figure 5 to the $x - y$ space is shown in Figure 6. It can clearly be seen that the two wanted lines are found with this method. The two dotted lines are the result of a CUSUM test of the raw data, and together they define the confining lines of the parking space.

FINDING THE CORRECT LINES

As can be seen from Figure 6, and from further tests with data from other experiments, the transform often produces several candidate lines. Experiments show that the strongest line is most likely one of the correct ones. Of 319 real world experiments with data collected from the Volvo S60 in Figure 1, only two failed. Then the knowl-

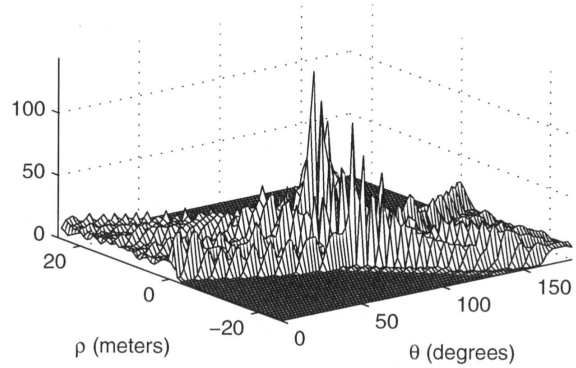

Figure 7: The Hough plane on a case with three parked cars

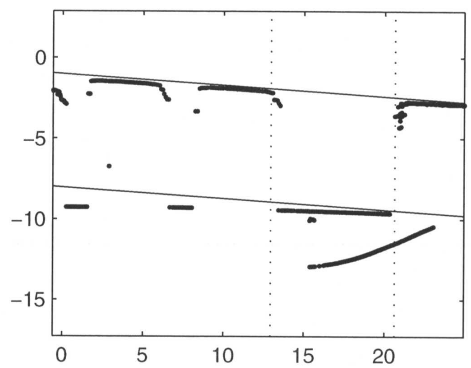

Figure 8: Retransformation of Figure 7 using the presented line searching

edge that the two lines is parallel or nearly parallel can be used to find the other one.

The used line searching algorithm can be summarized as:

1. Find the strongest line
2. Select all lines with the same or nearly the same θ as the strongest line found above
3. Pick the two strongest lines out of the selection

Using the algorithm above the two correct lines were found in the majority of the available test cases, two of them are illustrated in Figure 7 through Figure 10.

UNCERTAINTIES

In this paper a sensor echo is seen as a point in the $x-y$ space, which is an approximation. In reality an echo comes from an arc shaped region since the sensor has a cone shaped beam pattern.

According to [1] the arc shaped region can be approximated with a circle. This would "smear" the transformation of an echo along the θ axis in the $\rho-\theta$ plane. This is however not done in this work.

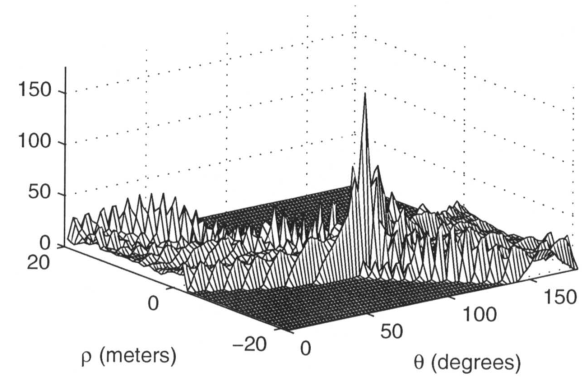

Figure 9: The Hough plane from a case with many spurioses

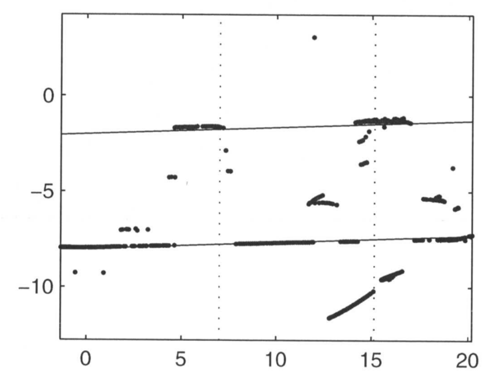

Figure 10: Retransformation of Figure 9 using the presented line searching

CONCLUSION

The results in this paper show that a weighted version of the Hough transform can be used to reliably detect two confinement lines of a parking space using data from a single ultrasonic sonar sensor. It is also suggested that a statistical method such as the CUSUM test on the same data give an approximation of the other two confinement lines. Further, an algorithm for selecting lines among the ones generated by the Hough transform is presented.

The presented work has also been tested on a large set of experiments, over 300 real world parking situations in varying conditions, and the results have been very reliable.

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