ABSTRACT

In this study, an intelligent parking assistance system with a function of reversing route guidance has been developed through the integration of trajectory arithmetic unit, steering wheel angle sensor, rear camera, and monitor. The key mathematical model of vehicle reversing trajectory is systematically established based on the theory derivation and experimental verification. This trajectory model is universal and applicable to almost types of vehicles just by replacing basic vehicle dimensions. The predicted trajectory can be instantaneously calculated according to the angle of steering wheel and then superimposed onto the image shown on the monitor to let the driver know beforehand where the vehicle will go. Besides estimated reversing route, the extension lines of vehicle width as well as the range lines are designed to provide the driver more information about the vehicle attitude and the distance between obstacles. In conclusion, the advanced parking assistance system developed in this work can make the parking behavior much easier and effectively enhance the safety via displaying the estimated guidelines on a monitor.

KEYWORDS

Parking assistance, trajectory guidance, reversing route, steering wheel angle

INTRODUCTION

Recently, with increasing consideration of vehicle safety, more and more advanced safety systems have been developed and gradually become standard equipments for new generation vehicles. The parking assistance is currently one of the most interested fields for advanced
safety vehicle (ASV) development. In general, for novices or motorists who rarely drive are not skilled in parking and reversing maneuvers. Although recently many new vehicles are equipped with rear ultrasounds and cameras [1], the assistance is still limited due to the lack of forecasting interaction between the vehicle and surroundings. In order to make the parking task safer and more convenient, advanced assistance technology has been gaining increasing attention from the car industry in the last couple years, such as trajectory guidance or automated parking technologies. For the near future, the general trend is rather to keep the drivers in control, but to assist them [2]. Therefore, the objective of this study is to develop an FPGA (field-programmable gate array)-hardware-based parking assistance system with three kinds of guidelines including the predicted reversing trajectory, the vehicle width extension line and the range line superimposed on the image from the rear camera. The operation flow of this parking assistance system is shown in Fig. 1.

![Fig. 1 The operation flow of the parking assistance system.](image)

**SYSTEM DEVELOPMENT**

**DEVELOPMENT PROCEDURE**

Fig. 2 shows the development procedures of this parking assistance system. The procedure mainly consists of five steps listed as follows:

- Establishing the mathematical model of the vehicle trajectory.
Transforming the trajectory data points from global to image coordinates and then distorting the projected trajectory to match up with the distorted rear image.

- Carrying out the rapid prototyping and the simulation verification by using the MATLAB/Simulink.
- Implementing the system on an FPGA (Field-Programmable Gate Array) hardware.
- Performing the on-vehicle road testing to verify its functionality.

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**TRAJECTORY MATHEMATICAL MODEL**

Figure 3 shows a simplified dynamic model of the vehicle [3]. Under the assumption of no slip for rear wheels, the velocity of the rear wheels in the lateral direction would be equal to zero and be expressed as

\[
\dot{y} \cos \theta - \dot{x} \sin \theta = 0
\]

Moreover, the center point \((x_r, y_r)\) of the vehicle rear axle with time in global coordinates can be given as follows.

\[
\begin{align*}
x_r(t) &= a \cdot \cot \phi \cdot \sin \left( \frac{v \cdot \sin \phi}{b} t \right) \\
y_r(t) &= -a \cdot \cot \phi \cdot \cos \left( \frac{v \cdot \sin \phi}{b} t \right) + c \cdot \cot \phi
\end{align*}
\]
Where $v$ is the vehicle speed, $\phi$ is the steering angle, and $a$, $b$ and $c$ are vehicle dimensions. From the geometric position relationship, the coordinates of the rear wheels can be further derived as following Eq. (3) and Eq. (4).

Left wheel:
\[
\begin{align*}
x_r(t) &= a \cdot \cot \phi \cdot \sin \left( \frac{v \cdot \sin \phi}{b} t \right) - d / 2 \\
y_r(t) &= -a \cdot \cot \phi \cdot \cos \left( \frac{v \cdot \sin \phi}{b} t \right) + c \cdot \cot \phi + d / 2
\end{align*}
\]

Right wheel:
\[
\begin{align*}
x_r(t) &= a \cdot \cot \phi \cdot \sin \left( \frac{v \cdot \sin \phi}{b} t \right) + d / 2 \\
y_r(t) &= -a \cdot \cot \phi \cdot \cos \left( \frac{v \cdot \sin \phi}{b} t \right) + c \cdot \cot \phi - d / 2
\end{align*}
\]

Where the parameter, $d$, is related to the vehicle tread.

**Fig. 3** The simplified vehicle dynamic model.

**COORDINATE CONVERSION AND DISTORTION**

After obtaining the trajectories of the rear wheels in global coordinates, the data points are multiplied by the transformation matrix, as shown in Eq. (5), to get converted to the camera coordinates, and then perspectively projected onto the 2-D image plane by using the focus length of the camera.
\[
\begin{bmatrix}
1 \\
X_c \\
Y_c \\
Z_c \\
\end{bmatrix}
= \begin{bmatrix}
R & T \\
0 & 1 \\
0 & 0 \\
0 & 0 \\
\end{bmatrix}
\begin{bmatrix}
X_w \\
Y_w \\
Z_w \\
1 \\
\end{bmatrix}
\] (5)

Where \([X_c, Y_c, Z_c]\) is the point in the global coordinates, \([X_w, Y_w, Z_w]\) is the corresponding point in the camera coordinates, \([R]\) is a 4x4 rotation matrix and \([T]\) is a 4x4 translation matrix. Since the rear camera adopted in this system is a wide-field camera, the predicted guidelines are further distorted to match up with the barrel-distorted rear image. The process for coordinate transformation with distortion is shown in Fig. 4.

![Fig. 4 The process for coordinate transformation with distortion.](image)

**RAPID PROTOTYPING AND SIMULATION VERIFICATION**

In this work, the Matlab/Simulink software is used to do rapid prototyping and further validate the trajectory mathematical model. Figure 5 shows the system simulation block diagram. The blocks mainly include parameter inputs, input interface, arithmetic kernel and output interface.

- Parameter inputs: steering angle, vehicle dimensions and camera parameters.
- Input interface: CAN (Controller Area Network) configuration, CAN receiver, image acquisition (S-function) tools.
- Arithmetic kernel: trajectory model, draw line tool, OSD (On Screen Display), image composition and resize tools.
- Output interface: video viewer, VGA interface.
The verification results by the Matlab/Simulink simulation are shown in Fig. 6 where the trajectories at the steering wheel angles of 0°, 180°, and 360° are presented as examples. It can be seen in Fig. 6 that the predicted trajectory are in good agreement with the actual reversing routes (white lines on the ground), i.e., the predicted and the actual curves are almost merged together.

**HARDWARE IMPLEMENTATION**

For the consideration of access to flexible adjustment and mass production, this advanced parking assistance system was implemented with an FPGA hardware platform as shown in
Fig. 7. The system hardware configuration generally consists of FPGA, video decoder, video encoder, microprocessor chip, CAN receiver, steering wheel angle sensor, camera and monitor as shown in Fig. 8. Figure 9 shows the practical function demonstration of this parking assistance system equipped on a test vehicle.

Fig. 7  The FPGA hardware platform.

Fig. 8  The system hardware configuration.

Fig. 9  The system function demonstration.
SUMMARY

In this paper, the advanced parking assistance system with three kinds of guidelines, i.e., the predicted reversing trajectory, the vehicle width extension line and the range line, has been developed based on an FPGA hardware platform and it is capable of going ASIC (Application Specific Integrated Circuit) mass production. This assistance system can make the parking behavior much easier and effectively enhance the safety via displaying the rear image with these estimated guidelines on a monitor.

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