Design of Lane Departure Warning System Based on Fuzzy Control Mode of Android System

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Abstract. Aiming at the unconscious lane departure behavior in the process of driving, a design scheme of lane departure warning system based on Android is proposed. STM32F103C8T6 is selected as the main control chip and CAN bus communication technology is used to collect vehicle information such as vehicle speed, steering angle and steering signal. Then Bluetooth module is used to transmit the data to the mobile phone for real-time processing. Taking GB/T 26773-2011 (Performance Requirements and Test Methods for Lane Departure Alarm System) as the design standard, the lane departure rate $\varepsilon$ and the time $T$ when the right front wheel crosses the lane line are considered as the input of the two-dimensional fuzzy controller, and the early warning level $W$ is considered as the output. When the driving deviation angle is $5^\circ$, the interval of the lane departure rate $\varepsilon$ is $[0.75, 1.35]$, and the interval of $T$ is $[0, 1.5]$. After normalized parameter processing, a certain fuzzy interval is set according to the driving habits of different vehicle drivers, and the fuzzy control algorithm with improved membership function is adopted for control, so as to improve the recognition rate of lane lines, reduce the early warning misjudgement rate and reduce the incidence of traffic accidents.

1. Introduction
With the rapid development of science and technology, lane departure warning system is widely used in vehicles [1]. As one of the active safety configurations of vehicles, lane departure warning system can prompt drivers in time for unconscious lane departure during the driving process of vehicles, so as to avoid traffic accidents caused by sudden change of driving track, resulting in vehicle property and personal injury [2-3]. The existing lane departure warning products are mainly divided into two categories [4-5]. One is the lane departure warning system provided by the original factory, which is mainly concentrated on high-grade cars, and economical cars are generally not equipped. The other is developed by the third-party manufacturers, which realizes lane departure identification by installing camera equipment. The price difference is large and the functions are uneven. What’s worse, it needs to refit and wire the entire vehicle line, which has certain potential safety hazards to the vehicle.

In order to improve the safety of vehicles and the popularity of lane departure warning system, this paper proposes a lane departure warning system design based on Android. The mobile phone is taken as the core of calculation, and the mobile phone camera is adopted to replace the dedicated video acquisition hardware to reduce the design cost of the lane departure system, and the lane departure warning of the vehicle is realized on the premise of not changing the vehicle line. It not only has high universality, but also can save cost.
2. Overall frame design of the lane departure warning system

Two conditions must be met to build the lane departure warning system based on Android system: the realization of lane departure system must collect vehicle state information such as vehicle steering signal, speed, steering angle, which is transmitted to the mobile phone CPU to calculate the real-time state of the vehicle. The identification of road information, that is, the identification and tracking of lane lines, is collected and processed in real time by the camera. The overall frame design is shown in Figure 1.

![Overall frame design of the lane departure warning system](image)

3. Hardware design of the lane departure warning system

Through the hardware design, the vehicle information is transmitted to the CPU of the mobile phone, and the driving condition of the vehicle is judged to provide judgment basis for lane departure identification. The hardware design should meet three requirements. The first is the function of reducing voltage. The power consumption of the vehicle is 12V, and that of the single-chip system is 3.3V. It needs to convert 12V to 3.3V. The second is having CAN communication, and it can read the vehicle speed, steering signal and corner signal through the vehicle CAN bus network. And the last one is the Bluetooth communication that is available to send vehicle information to mobile phones via Bluetooth. The main control chip is STM32F103C8T6, and the relevant circuit design is shown in Figure 2.

![Main control circuit diagram of the lane departure warning system](image)

3.1. Power system

The lane departure warning system uses on-board OBD diagnostic interface to supply 12V power, and uses REG1117-3.3 to convert 12V to 3.3V, which is provided to MCU module, Bluetooth module and CAN communication module.
3.2. CAN communication module
STM32F103C8T6 has its own CAN controller, which is compatible with the CAN 2.0 communication protocol of vehicles, by monitoring the CAN bus with no response and no error mark, and will not cause interference to the CAN bus system of vehicles. The transceiver uses TJA1050 to convert the logic level of the CAN controller into the differential level of the CAN bus.

3.3. Bluetooth communication module
In Bluetooth communication, the serial port USART of STM32F103C8T6 is used to send and receive instructions to control the information transmission of Bluetooth chip BC05. And BC05 is compatible with Bluetooth specification 2.0. It integrates Bluetooth radio frequency, Bluetooth Baseband controller and Bluetooth antenna.

4. Algorithm design of the lane departure warning system

4.1. Lane line model
For smartphones with Android system, due to space constraints, most of the phones use fixed focus lenses, and the phones are placed inside the cars to take images of the road ahead obliquely forward and downward. On a structured road, because of the perspective effect of the lenses, parallel lane lines form two intersecting lines in the image, and two intersecting curves will be formed in the curve. According to the curve design standard of Chinese expressway, in plain and hilly areas, the minimum curve curvature of expressway bends is 650 meters; and for expressways in mountainous areas, the minimum curvature radius is 250 meters. As shown in Figure 3, in the range of L equal to 2 meters, the error generated by the lane line is represented by a straight line model based on the minimum design standard curvature radius of 250 meters:

\[ \Delta S = R - \sqrt{R^2 - (L/2)^2} \approx 0.002m < 0.75m \]  

The 0.75m in formula (1) is the minimum safety distance specified in GB/T 26773-2011 (Performance Requirements and Test Methods for Lane Departure Alarm System). Therefore, using a simple straight line model for lane line can meet the requirements of the lane departure warning system.

![Figure 3. Error of lane line model.](image)

4.2. Fuzzy control design of the lane departure warning system

4.2.1. Determination of input and output variables
At present, most lane departure warning systems use distance or time as one of the warning thresholds, but there are many factors that affect the vehicle departure in the actual driving process. According to the performance requirements of GB/T 26773-2011 for lane departure warning on structured roads, the lane departure rate \( \varepsilon \) and the time \( T \) when the right front wheel crosses the lane line are taken as the inputs of the two-dimensional fuzzy controller, and the warning level \( W \) is taken as the output.

In the lane departure rate \( \varepsilon = \left| \frac{k_L}{k_R} \right| \), \( k_L \) and \( k_R \) are the slopes of the included angle between the left and right lane lines and the horizontal axis of the images respectively. According to reference [6], the theoretical domain of lane departure rate \( \varepsilon \) is [0.75,1.35] when the driving deviation angle is 5°. It
has been pointed out above that the simplified lane line model can meet the needs of lane departure warning. According to the calculation formula given in reference [7], the time when the front wheel crosses the lane line is

\[ T = \frac{D}{v \sin \theta} \]

among which \( D \) is the distance between the current position of the vehicle and the lane boundary line, \( y_R \) is the distance between the right front wheel of the vehicle and the right boundary line of the road, \( \theta \) is the vehicle deviation angle, and \( v \) is the current vehicle speed. According to reference [8], the theoretical domain \( T \) is set as \([0,1.5]\).

4.2.2. Fuzzy control model for lane departure warning

In reference [8], a simple triangle is used as the membership function of the fuzzy system. The boundary between the early warning levels is too absolute to consider the feelings of different drivers. In this paper, the improved algorithm is used to form a fuzzy model among the early warning levels, and the fuzzy area between the adjacent warning levels can be adjusted in real time. While improving the lane departure warning accuracy and reducing the false alarm rate, it can adjust the warning degree according to different driving habits. See Table 1 for warning levels corresponding to lane departure rate \( \varepsilon \) and the time \( T \) when the right front wheel crosses the lane line.

| Warning level    | Safest        | Safer         | Safe          | Dangerous     | More dangerous | Most dangerous |
|------------------|---------------|---------------|---------------|---------------|----------------|----------------|
| Lane departure rate | 0.95~0.95, 1.07 | 0.85~0.9, 1.07 | 0.85~0.95, 1.07 | 0.8~0.85, 1.14 | 0.75~0.8, 1.21 | <0.75, >1.35 |
| Crossing time/s  | 0~0.25, 0.25~0.50 | 0.5~0.75, 0.50 | 0.75~1.0, 0.25 | 1~1.25, 1.0 | 1.25~1.5      |

Standardize the lane departure rate and the time when the right front wheel crosses the lane line. Considering that the lane departure rate has a greater impact on vehicle departure than the crossing time, the weight is set to be 0.6 and 0.4 respectively. It is expressed by the normalized parameters \( x \).

\[
x = 0.6 \frac{\varepsilon_{\text{max}} - \varepsilon}{\varepsilon_{\text{max}} - \varepsilon_{\text{min}}} + 0.4 \frac{T_{\text{max}} - T}{T_{\text{max}} - T_{\text{min}}}
\]  

A certain fuzzy interval \( \Delta C \) is set between the adjacent warning levels, which is adjusted by the driver according to the driving habits of different vehicles. The six early warning levels are represented by membership functions in Figure 4. The value of \( x_1 \) and \( x_2 \) is determined by the values in Table 1 after standardized treatment, and \( X \) is a very dangerous limit value.

![Figure 4. Membership function diagram of the alert level corresponding to the input parameters.](image)

The input parameter \( x \) corresponds to the safest membership function is:
\[ \mu(x) = \begin{cases} 
1, & 0 \leq x \leq x_1 + \Delta C \\
\frac{1}{2} - \frac{1}{2} \sin \frac{\pi}{x_2 - x_1} (x - \frac{x_2 + x_1}{2}), & x_1 + \Delta C < x < x_2 + \Delta C \\
0, & x \geq x_2 + \Delta C 
\end{cases} \]

The input parameter \( x \) respectively corresponds to the safer, safe, dangerous, more dangerous membership functions are:

\[ \mu(n) = \begin{cases} 
0, & x \leq -x_2 + (nk + \Delta C) \\
\frac{1}{2} + \frac{1}{2} \sin \frac{\pi}{x_2 - x_1} (x - \frac{x_2 + x_1}{2}), & -x_2 + (nk + \Delta C) < x < -x_1 + (nk + \Delta C) \\
1, & -x_1 + (nk + \Delta C) \leq x \leq x_1 + (nk + \Delta C) \\
\frac{1}{2} - \frac{1}{2} \sin \frac{\pi}{x_2 - x_1} (x - \frac{x_2 + x_1}{2}), & x_1 + (nk + \Delta C) \leq x \leq x_2 + (nk + \Delta C) \\
0, & x \geq x_2 + (nk + \Delta C) 
\end{cases} \]

In the formula, the parameter \( k = \frac{1}{5}X \), \( n = 1, 2, 3, 4 \).

The input parameter \( x \) corresponds to the most dangerous membership function is:

\[ \mu(x) = \begin{cases} 
0, & x \leq -x_2 + (nk + \Delta C) \\
\frac{1}{2} + \frac{1}{2} \sin \frac{\pi}{x_2 - x_1} (x - \frac{x_2 + x_1}{2}), & -x_2 + (nk + \Delta C) < x < -x_1 + (nk + \Delta C) \\
1, & -x_1 + (nk + \Delta C) \leq x \leq x_1 + (nk + \Delta C) 
\end{cases} \]

In the formula, \( n = 5 \).

### 4.3. Program design of image gray processing and edge detection

#### 4.3.1. Program design of image gray processing

```c
void Gray(void) {
    // Process the sub-function to be gray.
    unsigned int Width, Height;
    unsigned int gray;
    unsigned int i, j;
    for(i=0;i<640;i++) { // Use double layers “For Cycle” to calculate every point in the object.
        for(j=0;j<240;j++)
            // Perform the gray scale conversion calculation gray value=0.3*red+0.59*green+0.11*blue.
            int gray = (77*Pic[i][j][0]+150*Pic[i][j][0]+29*Pic[i][j][0]+128) >> 8
            Pic[640][240][0]=gray;
        // Save the calculation results to the memory of the original image to save memory.
    }
}
```

#### 4.3.2. Program design of edge detection and limited range

```c
void EdgeDetection(void)
```
unsigned int i,j,k;
k=240;
// Reduce the horizontal limit of the first row, 240 points on the left and 240 points on the right.
for(j=1;j<239;j++)
{
    for(i=k;i<640-k;i++)
    {
        if(abs(Pic[i][j][0]-Pic[i][j-1][0])<20)
        // Judge the gray scale change with the left point.
        {
            Pic[i][j][0]=0; // The larger rate of change is at the edge of the object.
            continue; // Skip to calculate the next point.
        }
        if(abs(Pic[i][j][0]-Pic[i][j+1][0])<20)
        // Judge the gray scale change with the right point.
        {
            Pic[i][j][0]=0; // The larger rate of change is at the edge of the object.
            continue; // Skip to calculate the next point.
        }
        if(abs(Pic[i-1][j][0]-Pic[i][j-1][0])<20)
        // Judge the gray scale change with the upper point.
        {
            Pic[i][j][0]=0; // The larger rate of change is at the edge of the object.
            continue; // Skip to calculate the next point.
        }
        if(abs(Pic[i+1][j][0]-Pic[i][j-1][0])<20)
        // Judge the gray scale change with the lower point.
        {
            Pic[i][j][0]=0; // The larger rate of change is at the edge of the object.
            continue; // Skip to calculate the next point.
        }
        Pic[i][j][0]=255;
    }
}
Pic[k][j][0]=0; Pic[640-k][j][0]=0; // Add the frame.
k=k-1; // Downwards extend the scope to a certain extent.

5. Conclusion
In order to reduce the incidence of traffic accidents, this paper proposes a lane departure warning system based on Android. With the high performance of smartphones, the system cost can be reduced as much as possible, and the loading rate of lane departure warning system can be improved. The vehicle status information such as steering signal, vehicle speed, and steering angle is collected through the on-board CAN communication interface and transmitted to the CPU of the mobile phone. The lane lines are collected and processed by cameras for identification and tracking.

According to the requirements of GB/T 26773-2011 (Performance Requirements and Test Methods for Lane Departure Alarm System), the lane departure rate $\varepsilon$ and the time $T$ when the right front wheel crosses the lane line are taken as the inputs of the two-dimensional fuzzy controller, and the early warning level $W$ is taken as the output. When the driving deviation angle is $5^\circ$, the interval of lane deviation rate $\varepsilon$ is [0.75,1.35], and the interval of $T$ is [0,1.5]. After normalized parameter processing,
a certain fuzzy interval is set according to the driving habits of drivers of different vehicles, and fuzzy control algorithm is adopted for control, so as to improve the recognition rate of lane lines, reduce the early warning misjudgement rate and achieve the purpose of real-time early warning of lane departure.

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