Measurement of Road Slope based on Computer Vision

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Abstract. This paper proposes a driving road slope measurement algorithm to provide a reference for adjusting the vertical angle of headlights. It uses a combination of Canny Edge Detection and Hough Transform to process images from camera to detect and fitting lanes. The angle of ramp can be calculated by Mathematical Model.

1. Design background
Driving safely at night can be achieved by adequate lighting. However, for technical reasons, headlights cannot illuminate ramp in advance. Therefore, ramp is a blind area of vision for drivers at night.

Several works have been already made to improve automotive lighting systems. For example, Adaptive Front Lighting System (AFS), this system collects and processes information from vehicle sensors to regulate illumination and direction according to vehicle speed and road geometry. The shortage of sensors is that it cannot distinguish ramp in advance. Thus, it makes a lag in lighting regulation and makes effects on drivers. In contrast to sensors-based AFS, Computer Vision can obtain a reliable slope before going up. The road slope measuring method based on Computer Vision can be classified into two categories. The first category is processing grayscale image to detect a horizontal edge from light to dark which means a ramp in front. However, it requires flat roads. The second is detecting the bending angle of lanes. This paper focuses on road slope measurement algorithm in the second category. The algorithm includes image preprocessing, lane detection and fitting, as well as the mathematical model of angles.

2. Technical route
3. Technical realization plan

This technology intends to analyze three aspects: image preprocessing, lane detection, and pavement slope analysis.

3.1. Image preprocessing

In order to improve the efficiency and accuracy of the system, it is usually necessary to preprocess the original images. The preprocessing of this project includes three parts: setting the ROI area, image graying, and image enhancement.

Set the ROI area, and estimate the ratio of the effective area to the ineffective area based on parameters such as the safety distance, the height of the low end of the ramp, and the camera focal length. This not only guarantees the quality of the captured image but also processes the image within a safe distance. Figure 2 shows the setting of the region of interest in the original image. It can be seen that the setting of ROI can avoid the introduction of invalid data and discard the invalid part of the data.
Figure 2. Capture the ROI area from the original image.

Since the captured image is a color image, which contains three components R, G, B, and the value range of each component is (0, 255), it takes up a large space and is easily affected by external light. And each pixel of a grayscale image has only one component, which occupies a small memory space. In order to improve the speed of lane acquisition, the grayscale method is used to process the original color images. The conversion formula is given by:

$$\text{Gray} = \text{Green} \times 0.587 + \text{Blue} \times 0.114 + \text{Red} \times 0.299$$

(1)

In terms of image enhancement, the project intends to call OpenCV image processing functions to eliminate noise and enhance images. For eliminating image noise, you can use OpenCV's "smoothing" method for image processing, which is achieved by calling the function CV Smooth(). After setting the parameter “smoothtype” according to the actual situation of the camera and the image processing platform, the median filter is used to remove the random noise, and then Gaussian filter is applied to remove the Gaussian noise to meet the image requirements of the target detection algorithm.

3.2. Lane detection

Lane detection methods can be divided into three types: feature-based, model-based, and image-based. The feature-based lane detection technology mainly uses methods such as region growth, edge detection, and image segmentation to extract the feature information of lanes that are significantly different from the background such as brightness, color, texture, to achieve the purpose of identifying lanes. Model-based detection methods impose constraints on the detection process by setting road model parameters. The image space-based lane detection technology should theoretically have higher accuracy than the feature-based lane detection technology, but the actual application data is less, and the accuracy needs to be verified. In order to detect the lane of the road faster, this technology intends to use the canny edge detection algorithm to extract the edge gradient feature of the lane on the image, and use the probabilistic Hough transform to fit the lane. Then, according to the angle change of the lane, analyze the change of the road slope ahead.

The Canny algorithm is a recognized optimal multi-level edge detection algorithm. The Canny algorithm uses a Gaussian filter to smooth the image and filter out noise. Apply non-maximum suppression to eliminate spurious effects caused by edge detection. Apply Double-Threshold detection to determine the true and potential edges. Compared with the Sobel algorithm and the Laplacian algorithm, the canny method is less susceptible to noise interference and can detect real weak edges. It uses two different thresholds to detect strong edges and weak edges respectively, and only when the
weak edges and strong edges are connected, the weak edges are included in the output image. The extraction results of canny algorithm are shown in Figure 3:

![Canny edge detection result](image)

**Figure 3.** Canny edge detection result.

Hough transform is a method commonly used to recognize straight lines in machine vision. The principle is to use the duality of points and lines to convert a curve in the original image space into a point in the parameter space, and convert the curve detection problem in the original image into a problem of finding the peak value of the point in the parameter space, so that the overall characteristics are Detection becomes local feature detection.

In polar coordinates, use the parametric equation 4-15 to represent a straight line:

\[ \rho = x \cos \theta + y \sin \theta \]  

(2)

Among them, \( \rho \) represents the vertical distance from the origin of the straight line, \( \theta \) represents the angle from the x-axis to the vertical line of the straight line, and the value range is \( \pm 90^\circ \). In the polar coordinate representation, after the collinear points in the image coordinate space are transformed into the parameter space, they all intersect at the same point in the parameter space. At this time, the \( \rho \) and \( \theta \) obtained are the polar coordinate parameters of the straight line. When expressed in polar coordinates, the two collinear points \((x_i, y_i)\) and \((x_j, y_j)\) in the image coordinate space are mapped to the parameter space as two sinusoids that intersect at the point \((\rho_0, \theta_0)\), as shown in Figure 4.

![Mapping relationship](image)

**Figure 4.** Mapping relationship.

In the specific calculation, the parameter space can be regarded as discrete. Establish a two-dimensional accumulation array \( A(\rho, \theta) \). The range of the first dimension is the possible range of the image coordinate space, and the range of the second dimension is the possible range of \( \theta \) in the image.
coordinate space. In the beginning, $A(\rho, \theta)$ is initialized to 0, and then 1 is added to the array element $A(\rho, \theta)$ corresponding to each front spot $(x_i, y_i)$ in the image coordinate space. After all the calculations are completed, the maximum peak value of $A(\rho, \theta)$ is found in the parameter calculation voting results, and the corresponding $\rho_0$ and $\theta_0$ are the parameters of the linear equation with the largest number of collinear points in the source image. Probabilistic Hough transform is an improved straight line extraction algorithm based on standard Hough transform. When performing the probabilistic Hough transform, randomly select $N$ points in the image space, calculate the angular coordinate $(\theta, \rho)$, and then accumulate votes in the parameter space. When the maximum value of the vote is greater than the set threshold, it is judged to be a straight line, and the points on the straight line are removed from the image to reduce the amount of calculation; then the loop is executed until the maximum value of the $N$ feature points in the parameter space is less than the threshold, Output straight line. Because there are other elements in the image that will cause a great interference to the process, you can add constraints, such as the end coordinates of the line segment should be lower than the image, the slope of the left and right lanes, and tend to zero. The test results are shown in Figure 5:

![Figure 5. Probabilistic Hough Detection](image)

### 3.3. Pavement slope analysis

After the lane recognition is completed, the lane can be used to analyze the slope of the road surface. If there is a ramp on the road ahead, there will be an inflection point in the lane at the boundary of the road surface, and the slope of the lane before and after the inflection point will be quite different. Otherwise, the slope of the lane should be kept within a small range. Considering that the exact angle value is not needed in the actual process of driving, the curved road surface is ignored. Therefore, after the lane fitting is completed, $n$ points on the lane can be extracted, the left side is marked as $L_1, L_2, \cdots, L_n$, and the right side is marked as $R_1, R_2, \cdots, R_n$. Establish a coordinate system with the lower left corner of the picture, and then calculate the angle of the straight line between two adjacent points according to the coordinates of each point. Analyze the road slope according to the angle change of the lane, and mark the inflection point:

$$\theta_{L_i} = \tan^{-1}\left(\frac{L_{iy} - L_{iy}}{L_{ix} - L_{ix}}\right), i = 1, 2, 3, \cdots, n$$

$$\theta_{R_j} = \tan^{-1}\left(\frac{R_{jy} - R_{jy}}{R_{jx} - R_{jx}}\right), j = 1, 2, 3, \cdots, n$$

Judge whether there is a slope road ahead through the numerical change of angle $\theta_{L_i}, \theta_{L_j}$; if so, select the two nearest points $L_1, L_2$ ($R_1, R_2$) and the two furthest points ($L_{n-1}, L_n$), ($R_{n-1}, R_n$). Draw a straight line to calculate the coordinates of the inflection point of the lane. The establishment of characteristic points and slope analysis are shown in Figure 6.
By extracting the points on the lane, the inflection points $L_m$ and $R_m$ of the left and right lanes are calculated. Obviously, the slopes of the two road surfaces divided by the connecting point $L_m$ and $R_m$ are different. After the road surface is divided, it is necessary to calculate the vanishing point coordinates of the lanes of different roads. Similarly, through the extracted lane feature points, the last point where the left and right lanes converge is the vanishing point, and the vanishing point coordinates are calculated. By extracting the near points $L_1$ and $R_1$ on the left and right lanes, the far points $L_n$ and $R_n$, and the inflection points $L_m$ and $R_m$, the vanishing points $V1$ and $V2$ of the lanes on the two road sections are calculated. After obtaining the vanishing point, bring the vanishing point coordinates into the slope of the mathematical model below to calculate the road slope.

After obtaining the position of the vanishing point of the lane, a mathematical model can be established to calculate the angle of the ramp. Since the camera has a pitch angle, in order to facilitate the calculation, when building the model, the camera's imaging plane is kept perpendicular to the horizontal plane through rotation. The model diagram is shown in Figure 7.

In Figure 7, the dotted line shows the actual situation, and the solid line shows the rotated model. Among them, A is the vanishing point of the lane on the sloped road; b is the inflection point of the road; F is the camera. a and b are obtained after A and B are rotated. a' and b' are the projection points of a and b respectively. For the sake of calculation simplicity, the road surface BC is regarded as a horizontal road surface, and $\phi$ is the angle between the road surface AB and BC, which is the slope of AB. From the geometric relationship, the slope is

$$\Phi = \pi - \angle abF - \angle CbF$$

(5)
In triangle abF and triangle CbF, there are
\[ \angle abF = \pi - \angle a - \angle aFb \] (6)
\[ \angle abF = \angle \delta + \angle b'Fo \] (7)
Finally, after finishing the above formula
\[ \Phi = \angle aFb - \angle \delta - \angle b'Fo \] (8)
In this formula
\[ \angle aFb = \cos^{-1} \frac{f^2}{\sqrt{(y^2+f^2)(y_f^2+f^2)}} \] (9)
\[ \angle b'Fo = \tan^{-1} \frac{y_f}{f} \] (10)

4. Conclusion and prospect analysis
This paper studies Measurement of Road Slope, makes full use of road lane information, combined with image processing algorithm to find the slope area, then uses the Canny algorithm and Kirchhoff detection to identify, and finally establishes a mathematical model for calculation. Road gradient detection is an important development direction for car safe driving and one of the important technologies to increase car driving safety.
Measurement of Road Slope provides safety guarantees for car assisted driving systems and is of great significance to the development of the modern automobile industry.

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