The method for evaluating the coverage rate of roadside monitoring cameras in road areas

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Abstract. Accurately assessing the coverage rate of roadside monitoring cameras in road areas is crucial for intelligent transportation systems and road risk assessment. This paper presents a new method that uses Carsim software to simulate different camera tilt angles and road geometry conditions to evaluate the coverage area of roadside monitoring cameras. By adjusting the camera tilt angles and the curve radius of the road, the coverage effect under different conditions is analyzed, and affine transformation is used to calculate the actual coverage area. The research results show that this method can effectively fit the road area, providing theoretical support for the deployment of monitoring cameras in traffic.

Keywords: roadside monitoring cameras; coverage area; Carsim; camera tilt angle; road geometry; image processing

1. Introduction

As intelligent transportation systems continue to develop, roadside monitoring cameras play a crucial role in road safety management and traffic flow monitoring. By using real-time data from these cameras, traffic management departments can promptly detect and address traffic accidents, violations, and road obstructions, thereby effectively improving road efficiency and safety. However, the placement and coverage effectiveness of monitoring cameras directly impact their monitoring capabilities and effectiveness. Therefore, evaluating and optimizing the coverage rate of roadside monitoring cameras is particularly important.

Current research indicates that the coverage rate of roadside monitoring cameras is influenced by multiple factors, including the installation height and tilt angle of the cameras, the geometric shape of the road, and environmental conditions[1]. The complex combination of these factors makes accurately assessing and optimizing the coverage rate of monitoring cameras a challenging problem.

This study not only provides theoretical support for the placement of monitoring cameras but also offers new ideas for the overall optimization of intelligent transportation systems. By reasonably adjusting camera tilt angles and road geometry, we can significantly enhance monitoring effectiveness, ensuring road traffic safety and smoothness. Future research can further explore the impact of more variables (such as camera height and different weather conditions) on the coverage rate, providing a more comprehensive optimization plan for intelligent transportation systems[2].

2. Methodology

2.1 Road and Camera Modeling

This study uses Carsim software for road and camera modeling, primarily focusing on a 7.5-meter-wide dual-lane road model.Create a 7.5-meter-wide dual-lane road in Carsim, including straight segments and curves with different radii. Place the monitoring camera at the starting point of the road model and adjust the camera's tilt angle to simulate different monitoring perspectives.[3] Set parameters such as height, focal length, and field of view angle to meet standard monitoring specifications.[12]

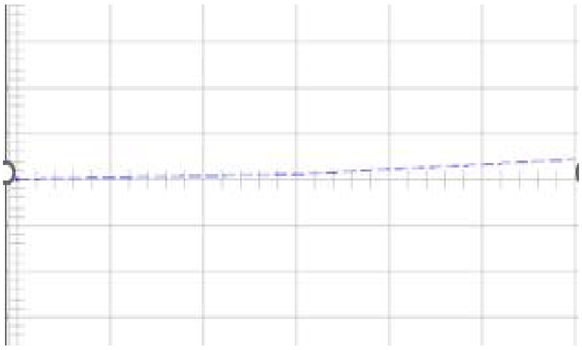
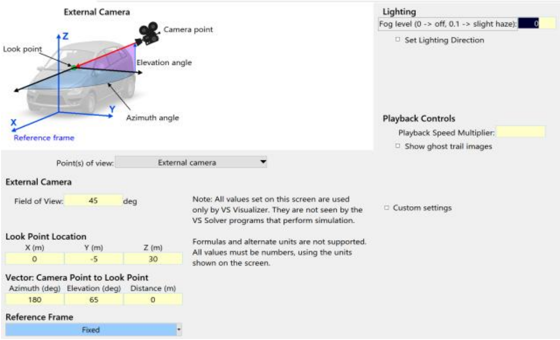


Fig.1. Road Modeling Scheme



Lighting

Fog level (0 -> off, 0.1 -> slight haze): 0

☐ Set Lighting Direction

Playback Controls

Playback Speed Multiplier:

☐ Show ghost trail images

Point(s) of view: External camera

External Camera

Field of View: 45 deg

Note: All values set on this screen are used only by VS Visualizer. They are not seen by the VS Solver programs that perform simulation.

Formulas and alternate units are not supported. All values must be numbers, using the units shown on the screen.

☐ Custom settings

Look Point Location

X (m)	Y (m)	Z (m)
0	-5	30

Vector: Camera Point to Look Point

Azimuth (deg)	Elevation (deg)	Distance (m)
180	65	0

Reference Frame

Fixed

Fig.2. Camera Model Construct

2.2 Image processing and road area coverage calculation

1) Acquisition and Preprocessing:

The captured road images are often affected by background interference. To suppress color interference and prepare for subsequent image segmentation, it is first necessary to perform grayscale processing on the images. Grayscale processing methods include the average weighting method, the maximum value method, and the average value method. We use the weighted average algorithm, where the red, green, and blue channel components of the color image are weighted according to the ratios of 0.3, 0.59, and 0.11, respectively, to obtain a grayscale image[4]. This approach better reflects human perception of color and improves the effectiveness of image segmentation.

2) Definition of Color Range and Mask Creation

To accurately identify the road area, we convert the image to the HSV color space, as the separation of color information and brightness information in HSV color space facilitates more precise color segmentation[3]. By defining the color range of the road area and using the color threshold segmentation method, a mask is created to extract the road area from the image. This step effectively filters out most background noise, making subsequent processing simpler and more accurate[5].

Fig.3.road images Fig.4.Image Grayscale Conversion

3) Image Denoising

Due to potential noise and small holes in the mask, we apply morphological operations for further processing. Morphological opening is used to eliminate small noise spots, while closing is used to fill small holes[6]. These operations can significantly improve the quality of the mask, making the extracted road area more coherent and complete.

4) Segmented Image

Apply the processed mask to the original image to highlight the road area. This step separates the road area from the background, preparing it for further analysis. The resulting segmented image shows the identified road area, which is crucial for calculating the coverage rate[7].

5) Coverage Area Calculation

Calculate the actual coverage area of the road using affine transformation. Affine transformation maps the pixels in the image to the actual road area, allowing for accurate coverage calculation. The specific steps are as follows:

Select reference points: Choose several reference points with known positions in the image (e.g., road markings) whose locations are known in both the image and the actual road[8].

Calculate the transformation matrix: Use these reference points to calculate the affine transformation matrix, converting image coordinates to actual physical coordinates.

Apply affine transformation: Apply the affine transformation to the entire image to obtain the image in actual physical coordinates[9].

Calculate pixel area: After affine transformation, the area of each pixel is approximately the same. The actual area of each pixel can be calculated based on the known area of the reference points. Specifically, if the area enclosed by the reference points is known[10], we can calculate the actual area of each pixel by counting the corresponding number of pixels in the mask.

Calculate total coverage area: By counting the total number of pixels within the road area and multiplying by the actual area of each pixel, the coverage area of the road is obtained.

Through these steps, we can accurately extract the road area from the image and use affine transformation to calculate its actual coverage area. This provides the foundational data for further analysis and optimization of the placement of monitoring cameras.

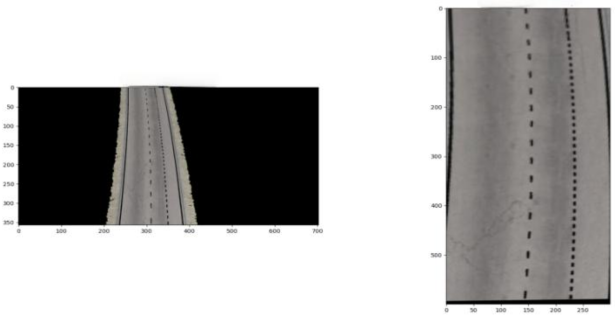


Fig.5 Affine Transformation

2.3 Experimental Design

In the experimental design, the primary adjustments involve the camera's tilt angle and the road's horizontal curve radius to study the coverage effect under different conditions.

To systematically study the impact of camera tilt angle and road curve radius on the coverage rate of roadside monitoring cameras, this research designs a series of experiments. The specific steps are as follows:

Set Camera Tilt Angle: In the experiments, we set different camera tilt angles, including 20°, 35°, 50°, and 65°.

Modify Road Curve Radius: To simulate the monitoring effect under different road geometry conditions, we created road segments with various curve radii.

Image Acquisition: After setting different camera tilt angles and road curve radii.

Data Collection: From the acquired images, we extract coverage data.

3. Results

3.1 Presentation of road area coverage data

The experimental data are shown in the table below, presenting the coverage area under different combinations of camera tilt angles and road curve radii:

Tab.1 Coverage Area Table

angle radius	**Φ=20°**	**Φ=35°**	**Φ=50°**	**Φ=65°**
R=250	659.4368	193.283	100.164	66.7776
R=500	756.812	189.090	98.057	65.8874
R=750	734.553	186.977	97.940	65.1081
R=1000	730.103	185.412	96.42	64.585
R=2500	718.314	183.817	94.28	63.107
R=5000	705.299	182.297	93.17	62.869
straight	693.176	181.913	92.956	62.532

3.2 Regression Analysis

To better understand the impact of camera tilt angle (φ) and road curve radius (R) on the coverage area, we conducted a regression analysis. Regression analysis helps quantify the contribution of each variable to the coverage area and clarifies the trend of coverage rate changes under different conditions. Below is the detailed analysis results.

We first attempted the simplest linear regression model, which assumes a linear relationship between the coverage area, curve radius, and tilt angle. The mathematical expression of the linear regression model is:

$$Coverage\,Area = 843.509 - 0.000523 \times R - 13.591 \times \phi \tag{1}$$

By fitting the experimental data using the least squares method, the regression coefficients obtained are as follows:

$\beta 0=843.509$: Represents the coverage area when both RRR and ϕ are zero[10].

$\beta 1=-0.000523$: Indicates that for each unit increase in the curve radius RRR, the coverage area decreases by 0.000523 square meters. The effect of the curve radius on the coverage area is negative, meaning that as the curve radius increases, the coverage area slightly decreases.

$\beta 2=-13.591$: Indicates that for each unit increase in the camera tilt angle ϕ, the coverage area decreases by 13.591 square meters[12]. This shows that the tilt angle has a significant impact on the coverage area, with the coverage area decreasing substantially as the tilt angle increases.

4. Conclusion

This study used Carsim software to simulate road coverage under different camera tilt angles and road geometry conditions, providing a detailed analysis and regression modeling of the coverage area. Accurate assessment of the coverage rate of roadside monitoring cameras is crucial for the maintenance and planning of intelligent transportation systems. Different methods offer complementary insights, and their combination can produce more comprehensive predictive information. The main conclusions are as follows:

As the radius increases, the coverage area starts to decrease. However, it should be noted that at very small radii, the coverage area might decrease due to the limitations of the monitoring camera's horizontal angle observation.

At larger tilt angles (e.g., 35°, 50°, and 65°), the coverage area gradually decreases with the increase in curve radius. This indicates that at these larger tilt angles, the camera can better cover the near-field area, but as the distance increases, the limitation of the viewing angle leads to poorer coverage effectiveness.

There is a significant interaction between curve radius and tilt angle, meaning the impact of the tilt angle on the coverage area changes with the curve radius. This interaction suggests that in practical applications, these two variables must be considered together to optimize camera placement[9].

Through polynomial regression analysis, a predictive model of the coverage area was established. The regression coefficients indicate that the linear, quadratic, and interaction effects of curve radius and tilt angle significantly affect the coverage area.

Acknowledgements

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