

# Evaluation Method for Road Area Coverage of Roadside Surveillance Cameras

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**Abstract.** As the number of surveillance cameras has increased rapidly, the issues of coverage blindness, coverage overlap and lack of vision resulting from an irrational surveillance layout have become increasingly prominent. This has led to a waste of resources and a reduction in surveillance quality. The conventional methodology for evaluating road coverage is inadequate for accurately assessing the actual monitoring capacity of the camera. In light of the aforementioned issues, this paper puts forth a novel road coverage assessment method based on the monitoring camera perception model. This approach integrates the monitoring coverage calculation methods in two-dimensional and three-dimensional spatial dimensions, considers road coverage under both single and multiple monitoring deployment scenarios, and employs GIS spatial analysis technology to achieve a comprehensive assessment of the monitoring camera network coverage. The findings demonstrate that the proposed methodology is capable of accurately calculating the coverage of surveillance cameras under diverse pitch angles and the extent of duplicate coverage areas in multi-camera deployments. It enhances the overall coverage and precision of the surveillance network, and provides a scientific foundation and practical guidance for the design and planning of road surveillance networks.

**Keywords:** Coverage calculation, surveillance cameras, GIS spatial analysis.

## 1. Introduction

The advancement of intelligent transportation systems has led to an increased reliance on roadside surveillance cameras for traffic management, safety monitoring and accident prevention [1]. However, traditional methods for assessing the coverage of roadside surveillance cameras are often based on coverage [2] or probabilistic models [3], which are unable to fully reflect the actual surveillance capability of cameras in relation to targets. In particular, cameras situated at different locations can form different perspectives on the same target, and the camera's perceptual ability is affected by a variety of factors, including target size, geometric structure and observation distance. Consequently, there is a pressing need to develop accurate methods for assessing the monitoring capability of roadside surveillance camera networks in relation to road areas.

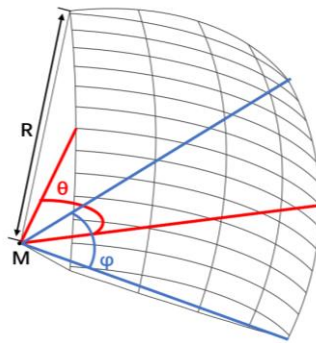
At present, a considerable number of researchers are combining GIS and video surveillance systems with the objective of enhancing the quality of coverage and operational efficiency of the surveillance system [4, 5]. This represents a viable approach for addressing the aforementioned issue. In light of the above, this paper puts forward a methodology for assessing the coverage of roadside surveillance cameras. This methodology is based on the surveillance camera perception model and takes into account a number of factors, thereby enabling a more accurate description of the camera's actual monitoring capability of the target. Furthermore, the paper introduces the GIS spatial analysis technology, which allows for the comprehensive assessment of the coverage of the roadside surveillance camera network through the construction of a reasonable scenario model. This methodology provides a new idea and methodology for the design and planning of the roadside surveillance system.

## 2. Methodology

### 2.1. Road and Camera Modeling

#### 2.1.1. Camera Model

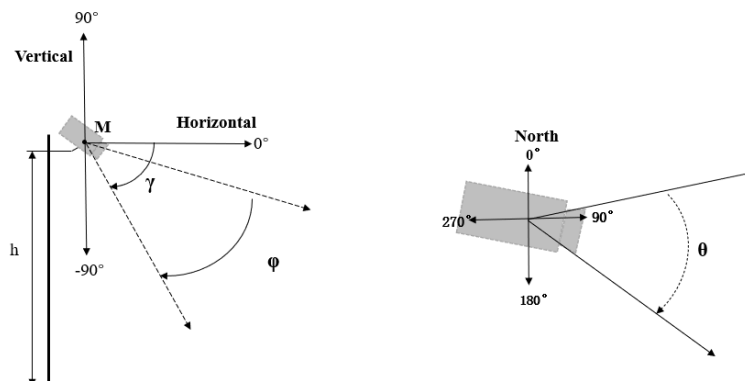
In order to evaluate the perceptual ability of surveillance cameras, previous researchers have typically employed 2D Boolean models with directional selectivity. However, in practical applications, the deployment of surveillance systems must also consider 3D spatial factors, such as the installation height, camera pitch angle, and so forth. Consequently, the perceptual model should accurately express the spatial coverage of the surveillance, which is conducive to promoting the application of theoretical research. The 3D directed perception models of video surveillance that are most commonly employed in current research include cones, prisms, spherical angular cones and other models [6, 7]. Fig. 1 provides a graphical representation of the fundamental model of the Spherical Angular Cone-Directed Perception Model. The mathematical model can be represented by four sets of parameters, designated as  $(M, R, \theta, \varphi)$ . In this model,  $M(x, y, z)$  represents the 3D spatial coordinates of the monitoring point,  $R$  denotes the radius of perception of the monitoring point,  $\theta$  is the horizontal directional or azimuthal angle, and  $\varphi$  is the vertical field-of-view angle, which takes the range of  $\theta \in [0, 360]$ , and  $\varphi \in [-90, 90]$ .



**Figure 1.** Spherical Angular Cone-Directed Perception Model

#### 2.1.2. Scene Model

The GIS point, line, and surface geographic elements are employed to construct a road surveillance model, which represents the location of the surveillance camera as point elements, while the experimental road is depicted through surface elements. By embedding these geographic elements into the same coordinate space, the coverage of the surveillance camera's roadway area is computed through the coverage computation method of the perceptual model. Fig. 2 depicts the representation of the target elements within the experimental area. The surveillance point is located on the left pole (at  $M$  in the image). The direction of the field of view is oriented towards the right side, thereby enabling the offset surveillance point to be controlled in terms of height, horizontal direction, and vertical angle.



**Figure 2.** Scene model

## 2.2. Road Area Coverage Calculation

The accurate calculation of the area of roadway covered by each surveillance camera in highway surveillance systems represents a complex task that necessitates a comprehensive examination of several factors. These include the camera's mounting location, its perceptual capability model, the camera configuration itself, as well as the obstacles in the surrounding environment that may impede the line of sight. Given the diversity and dynamics of these factors, direct and accurate computation is often both time-consuming and difficult to achieve. Consequently, in practical applications, a simplified calculation formula or model is typically employed to approximate the estimation of the road coverage area of each surveillance camera, in order to enhance efficiency and feasibility. This approach considers the fundamental parameters of the camera, including the horizontal and vertical viewing angles and mounting height, to rapidly obtain a relatively precise estimation of the coverage area.

### 2.2.1. Single-camera Coverage

The term "coverage area" is defined as a circular region, as illustrated in Fig. 3, with a radius of  $r$ , an angle of  $\alpha$ , and a road width of  $d$ . For a single camera  $i$ , its coverage area  $S_i$  can be expressed as:

$$S_i = \frac{1}{2} \alpha_i (2r_1 r_2 - 2r_1^2) \quad (1)$$

Where  $r_1$  is the radius at which the surveillance camera intersects the road,  $r_2$  is the maximum observation radius of the camera, and  $\alpha_i$  is the observation angle of camera  $i$ .

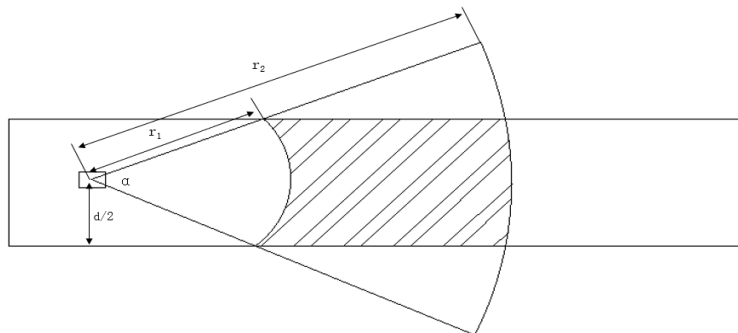


Figure 3. Surveillance camera coverage area

### 2.2.2. Multi-camera Coverage

In order to ensure comprehensive coverage, it is essential to consider the overlapping areas between cameras when calculating the total coverage area of a multi-camera network. In the case of a network comprising  $N$  cameras, the total coverage area,  $S_{total}$ , can be calculated using the following formula:

$$S_{total} = \bigcup_{i=1}^N S_i - \sum_{i=1}^N \sum_{j=i+1}^N S_{ij} \quad (2)$$

Where  $S_{ij}$  is the area of the overlap region between camera  $i$  and camera  $j$ . The calculation of the overlap area is contingent upon the specific position and observation angle of the monitoring camera. In practice, the direct calculation of the overlap area may be unwieldy; therefore, it can be approximated and estimated through simulation or experimentation.

## 2.3. Experimental Design

### 2.3.1. Parameter Design

The production of the vector dataset, the processing of the dataset, and the checking of the experimental results in this experiment are primarily accomplished with the assistance of GIS software. The experimental parameters are principally divided into two categories: those pertaining

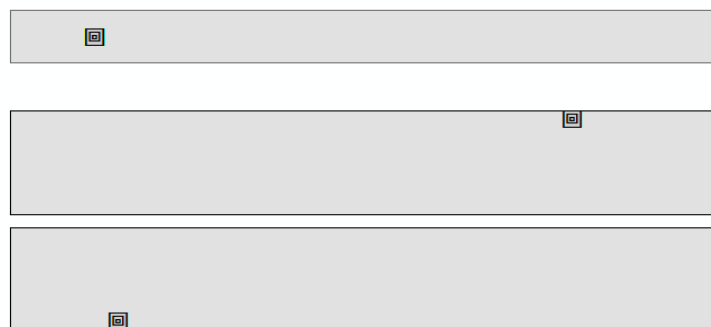
to the monitoring perception model and those pertaining to the scene model. The parameters of the experimental model are set as follows:

**Table 1.** Experimental model parameters

Camera Model Parameter		Value
Camera Height $h/m$		6
Horizontal field of view $\theta/^\circ$		60
Vertical field of view $\varphi/^\circ$		45
Radius $R/m$		50
Scene Model Parameter		Value
Single-camera	Number of roads	1
	Road length	100
	Road width	7.5
Multi-camera	Number of roads	2
	Road length	100
	Road width	15

### 2.3.2. Scene Design

In this experiment, the experimental road area is defined by GIS, and the camera positions are distributed in the area according to a specific strategy, as illustrated in Fig. 4. In the deployment of a single surveillance camera, the relationship between the pitch angle of the camera and the coverage area is considered, and the spatial analysis tool of GIS is utilised to determine the appropriate angle of a single surveillance point. In the deployment of multiple surveillance cameras, the collaborative strategy is considered, and the spatial analysis function of GIS is utilised to calculate the coverage area and the overlapping area, thereby providing a reference for optimising the layout of surveillance points. The spatial analysis function of GIS is employed to calculate the coverage area and overlapping area of the surveillance points, thereby providing a reference point for optimising the layout of the surveillance.



**Figure 4.** Experimental scenario

## 3. Results

### 3.1. Presentation of Road Area Coverage Data

Based on the road network data, candidate surveillance point data, sector plane data, and other relevant information, specific coverage area values are calculated. The aforementioned values will directly reflect the monitoring capability and effectiveness of the surveillance system. Furthermore, these results will serve as a crucial basis for evaluating the effectiveness of the surveillance system.

#### (1) Single surveillance camera coverage

In accordance with the stipulations of the experimental design, the location of the camera and the parameters of the experimental model have been determined. The experimental simulation has yielded the road coverage area of the camera under disparate pitch angles (-20 degrees to -50 degrees),

as illustrated in Fig. 5. The road coverage rate under varying camera pitch angles has been ascertained through the calculation of the area of each area.



**Figure 5.** Coverage area for different camera elevation angles

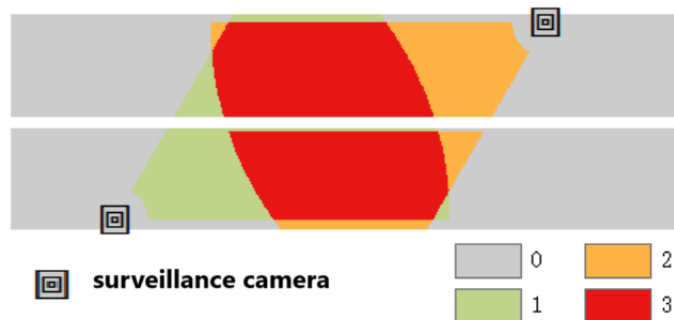
The grey portion of the figure signifies that the road monitoring is not encompassed, whereas the coloured sections within the sector represent the effective coverage of the monitored road sections. Additionally, the coverage area of the monitoring points under varying pitch angles is illustrated by the combination of different coloured facets. For instance, the coverage area of camera 1 encompasses Area 5 and 6. The table below presents the results of the analysis of the coverage area and coverage rate of the monitoring network at different pitch angles.

**Table 2.** Coverage for different camera elevation angles

Camera Numble	Elevation Angles	Area Number							Coverage Area (m <sup>2</sup> )	Coverage Rate
		0	1	2	3	4	5	6		
1	-20°	0	0	0	0	0	1	1	255.99	0.332738
2	-30°	0	0	0	0	1	1	1	303.07	0.393929
3	-40°	0	0	0	1	1	1	1	328.44	0.426902
4	-50°	0	0	1	1	1	1	1	341.98	0.444502
5	-60°	0	1	1	1	1	1	0	138.28	0.179729
Coverage Area (m <sup>2</sup> )		420.40	6.98	13.54	25.37	47.08	45.31	210.68	769.35	

(2) Multi-surveillance camera coverage

In accordance with the stipulations of the experimental design, the placement of multiple cameras and the corresponding experimental model parameters have been established. The experimental simulation has yielded the road coverage surface area of multiple monitoring cameras, as illustrated in Fig. 6. The total road coverage of multiple monitoring cameras has been determined by calculating the area of each surface area.



**Figure 6.** Multi-surveillance camera coverage area

The grey portion of the figure (Area 0) signifies that the monitoring is not encompassed by the road section. The remaining coloured sections within the sector represent the effective coverage of the monitoring of the road section. The effective area of camera 1 comprises the green (Area 1) and red area (Area 3). The effective area of camera 2 consists of the yellow (Area 2) and red area. The results of the multi-surveillance camera network of the area of coverage, coverage, etc., are presented in the following table.

**Table 3.** Multi-surveillance camera coverage

Camera Number	Area Number				Coverage Area (m <sup>2</sup> )	Coverage Rate
	0	1	2	3		
1	0	1	0	1	1072.51	0.444076
2	0	0	1	1	1064.80	
Coverage Area (m <sup>2</sup> )	1685.895	281.91	274.20	790.60	3032.61	

### 3.2. Analysis of Experimental Results

In this experiment, the coverage area of a single roadside surveillance camera was analysed at varying pitch angles. The findings demonstrate that the surveillance camera's coverage area undergoes a notable alteration in response to changes in pitch angle. A smaller pitch angle brings the camera's coverage closer to the ground, thereby facilitating the capture of road details at close range. Conversely, a larger pitch angle increases the coverage at long range, although it also reduces the coverage of the close range area. The analysis of the multi-camera network revealed that there is a degree of coverage overlap between nearby cameras, particularly in instances where the coverage area is extensive. In the future, the placement and angle of the camera can be optimised in order to effectively reduce the overlap area and improve the overall coverage. By configuring the pitch angle and position of multiple cameras in a reasonable manner, the road coverage can be greatly improved, thus achieving a more comprehensive monitoring effect. This will help to improve the coverage capability and effectiveness of the monitoring system in practical applications.

## 4. Conclusion

This paper presents a comprehensive study of the roadside surveillance camera's road coverage assessment method and proposes a novel surveillance camera-based perception model. The model integrates the key factors, namely the location, sensing direction and sensing radius of the surveillance camera, and introduces the height of the surveillance point and the elevation and pitch angle in 3D space when calculating the coverage area. This allows for a more accurate assessment of the coverage capability of the surveillance camera. The method has been demonstrated to be effective in determining the optimal coverage of surveillance cameras under different pitch angles, thereby providing a scientific basis for optimising the deployment and adjustment of cameras. The findings demonstrate that the method has considerable potential for application in the field of road surveillance, with the capacity to enhance the scope and reliability of the surveillance network. This provides a significant theoretical foundation and practical reference point for the design and assessment of road surveillance networks.

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