Modeling camera coverage using imagery techniques for surveillance applications

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Modeling Camera Coverage Using Imagery Techniques for Surveillance Applications

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***Abstract*—Modeling the camera coverage is evidently indispensable to meet the requirements of a variety of visual sensor related applications. It is critical to be able to compute the camera coverage and to plan the related application accordingly. However, it is well known that camera coverage can be modeled geometrically. In contrast, tackling the camera visibility in arbitrary scenario is usually the challenging part of the model. This work illustrates the theoretical bases of camera modeling. In the same context, the paper introduces a camera coverage model based on a combination of imagery and computer graphic techniques. The imagery part of the model handles the computations of the camera coverage in an arbitrary digitized two dimensional map, while the camera visibility is traced based on computer graphics line drawing algorithm. The proposed model is capable of computing the camera coverage area in highly occluded scenes.**

***Index Terms*- Camera coverage area, visibility, visual surveillance.**

I. INTRODUCTION

Capturing the camera coverage information is a fundamental element in a variety of applications such as offline sensor planning, optimal camera placement, camera selection and camera reconfiguration. The recent emergence of camera modeling is attributed to the acquisition of visual data for such applications [1].

Relying on the camera geometry, the coverage area is well defined in a two and three dimensional space. However, handling the visibility in arbitrary scenes is usually the challenging part of the model. Throughout the paper, the visual sensor visibility and coverage area for visual surveillance applications is considered. Moreover, the concept of the camera coverage and visibility is well explained and a number of recent literatures regarding the camera modeling are reviewed.

The contribution of this work is to introduce a flexible camera model based on a combination of imagery techniques and a Bresenham line drawing algorithm. Such combination supports the calculation of the coverage area while tackling the visibility in highly occluded scenarios. The strength of the model comes from its adaptive manner of handling different complex scenes.

The rest of the paper is organized as follows; the second section presents the model related parameters. The third section illustrates the recently published related literature. The fourth section demonstrates how the model tackles the camera coverage area and visibility. Finally, the result of applying the model is discussed in the fifth section. The conclusion and the future direction of this research are demonstrated in the sixth section.

II. THE MODEL RELATED PARAMETERS

Camera specifications are the keystone of modeling the visual sensor behavior. The modeling of the CCTV cameras requires determining preciously some of the related sensor specifications.

A. The Focal Length

The focus of our study is the pinhole camera model. This model assumes that all camera rays pass through a single point, the view point and that there is a linear relationship between image point position and the direction of the associated camera ray. That relationship can be expressed via a so-called calibration matrix *(K)* where its basic form of this matrix depends on two intrinsic parameters [2]:

$$K = \begin{pmatrix} f & 0 & x_0 \\ 0 & f & y_0 \\ 0 & 0 & 1 \end{pmatrix} \tag{1}$$

where f is the focal length measured in pixel dimensions, and (x_0, y_0) are the coordinates of the principal point [2]. Thus, the focal length of a camera determines the capability of magnification. A lens with a shorter focal length will be able to "see" a wider view of a scene than can a lens with a longer focal length, which would see a narrower view of the scene, but at a higher level of magnification.

B. Field of View

The field of view is a calculated measure that defines the maximum visible region from a camera. In that context, the camera coverage is limited by its visual distance and visual angle. Those angles are determined based on the lens type and image sensor size. This definition leads to a separate vertical and horizontal fields of view in the camera specifications since they are depend upon the height and width of the image sensor respectively.

Practically, the normal value for the horizontal field of view is around 50° but for specialized cameras it will range up to 110° [3].

Fig.1 (a, b) shows a visual realization of the camera's field of view in two and three dimensions respectively, where α and β are the vertical and horizontal angles [1, 3, 4].

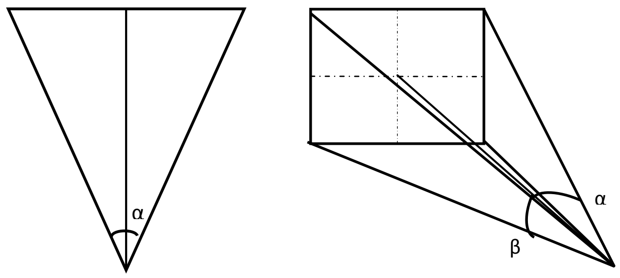

Fig. 1. Field of view & effective range of the camera. (a) Two dimension representation of the field of view. (b) Three dimension representation of the field of view.

C. Spatial Resolution

The spatial resolution of the camera is defined as the number of pixels utilized in construction of a digital image. Images having higher spatial resolution are composed with a greater number of pixels than those of lower spatial resolution i.e. higher spatial resolution captures more details and produces sharper images[5]. Factors such as sensor array type and size may have a serious impact on perceived sharpness regardless of actual pixel count. High resolution cameras can require proportionally brighter light sources [5].

D. Sensor Type

The sensor is the device that actually 'records' the scene view, with current cameras having either CCD (charge coupled device) or CMOS (complimentary metal-oxide-semiconductor) sensors. Sensors have both different sizes, which can change the field of view, and different pixel densities which affect the resolution [6].

III. Related Work

The main goal of the camera model is to evaluate the coverage of some region of a given space. Some applications have specific objectives and require attention when constructing their coverage models. Generally, in sensor planning the objective of the camera placement is to find a viewpoint which adequately covers the monitoring requirements for a given space. Typically, the objective is to search for either the solution with maximum coverage given a fixed cost (or number of cameras), or the solution with minimum cost yielding some maximum coverage. Through this section we look at the geometric modeling of the camera. We starts by the coverage area then revise the concept of visibility and finally illustrate the applications of the existing models.

A. The coverage area

The coverage area of the camera in visual surveillance can be categorized as follows[1]: The first category consider the topology of the modeling space. The coverage area is taken as a set of discretized points $\{v_i: i = 1, ..., N_c\}$, the discretized points are then mapped to a set of target space points $\{q_j: j = 1, ..., N_p\}$, Where the N_c and N_p are sizes of discretized camera space and target space [7, 8].

The second category geometrically undertakes the calculations of the set of the points included in the camera field of view using the camera geometry. The camera specification forms the initial inputs of the model, and the target is to geometrically generate a polygon/cone that represents the camera coverage area in two or three dimensional space respectively.

In this work, we adopted the geometrical based camera coverage calculation for modeling the camera coverage. Fig. 2 shows the projection of the field of view with respect to the various camera parameters. As shown in Fig. 2, the focal length of the camera and the image sensor size play a basic role in the field of view calculation. However, the generated field of view is relied on the set of geometrical equations as follows [9]:

$$\alpha = 2\arctan(\frac{w_I}{2f}) \tag{2}$$

$$FoV = \frac{1}{2} \times 2r \times \tan(\frac{\alpha}{2}) \times r \tag{3}$$

$$FoV = \frac{1}{2} \times 2r \times (\frac{w_I}{2f}) \times r \tag{4}$$

$$FoV = r^2 \times (\frac{w_I}{2f}) \tag{5}$$

$$r = \frac{f \times h_O}{h_I \times p} \tag{6}$$

$$FoV = \frac{1}{2}(\frac{w_I \times h_O^2}{h_I^2 \times p^2}) \tag{7}$$

Where:

FoV	The field of view
α	The angle of the field of view.
r	Camera effective range.
m	The width of the camera effective range.
f	Lens focal length.
w_I	Image sensor width.
h_I	Image sensor height.
h_O	Object height.
p	Minimum percentage of the object height of the image.

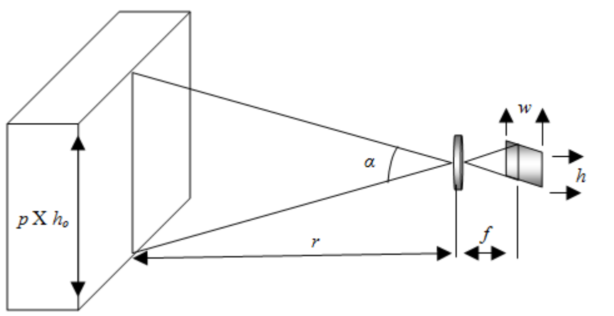

Fig. 2. The relation between the variables in the field of view and effective range formulas.

B. The camera visibility

Object visibility refers to identifying the portions of the object observable from a certain position of an observer. The notion of visibility has also been used extensively in the context of the art gallery problem in computational geometry. Today visibility is used in many fields of computer science including robotics, computer vision, and computer graphics [10].

Determining the visible region of a geometric object from a given source under various constraints is a well-studied problem in computational geometry. The visibility polygon V (q) of a point q in a simple polygon P is the set of all points of P that are visible from q [10]. In other words:

$$V(q) = \{p \in P \mid q \text{ sees } p\} \tag{8}$$

In the other hand, in computer graphics literature, the camera visibility is categorized based on its domain. Accordingly, the lines intersecting a point in three dimensions can be described by the point of intersection with the viewing plane [11].

As general computer graphics deals with the following visibility categories when considering the issue of visibility:

- Visibility from a point
- Visibility from a line segment
- Visibility of a polygon

The problem of a point-to-region visibility aims to classify a region as visible, invisible or partially visible with respect to a given viewpoint. The area labeled visible if the straight line from the given view point to farthest point in the area is not intersected with occluding objects [7]. A well known extension of the point to regain visibility is visibility maps. The visibility map is a data structure that describes the projection of the visible scene onto the image plane. It is a planner graph in which the vertices, edges and faces are annotated with the corresponding vertices, edges and faces of the scene. The concept of visibility maps is implemented in this work to illustrate the camera visibility in two dimensional image plane.

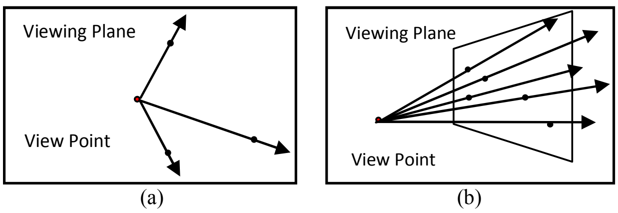

Fig. 3. The relation between the variables in the field of view and effective range formulas.

For the visual sensor visibility, the observable area is restricted by the geographical features as well as the attributes of the sensor. So the visible area from a certain point with coordinates (x, y, z) can be defined as the set of points on a surface D that are visible from v considering some maximum distance R from v. Formally:

$$\phi(v) = f(v, D, R) = \{\delta \in D \mid d(v, \delta) \le R\} \tag{9}$$

Where:

v	Viewpoint.
δ	The point to be observed.
D	Plane.
R	Distance consideration.

The visibility computation in visual sensors is based on the line of sight from the sensor to the point under investigation. Two points are considered mutually visible if and only if the line segment connecting these two points is not occluded by any kind of visibility, preventing obstacles such as building blocks, trees, walls… etc [11].

C. The application of camera modelling

Besides the surveillance application, camera modeling has been used successfully in a variety of applications such as camera selection, camera reconfiguration and camera calibration. Numerous models have been proposed to simulate the camera functionality in those applications. Throughout this section we attempt to review the related literature regarding modeling the camera coverage for solving the placement problem.

The placement problem is undertaken as a classic art gallery problem [3, 12, 13], with the assumption of unlimited visibility. This assumption of unlimited guard visibility restricts the implementation of the AGP based algorithms in the field of visual sensor placement because the camera visibility is bounded by its distance and angle [10, 14]. Set covering problem is proposed by [15, 16] to model the placement problem, but developing a general solution is proven to be limited. However, set covering problem may require excessive resources not available to the service providers [14]. In [8, 17] the problem has been approached through a more realistic two-dimensional model. Extending the visibility to include dynamic occlusion is also addressed in [18] and [19].

IV. Camera Model

The coverage modeling relies strictly on the camera specification. We implemented in this work a two dimensional image to represent the input map. Each input map includes two elements namely, the observable area and the objects contained in that area.

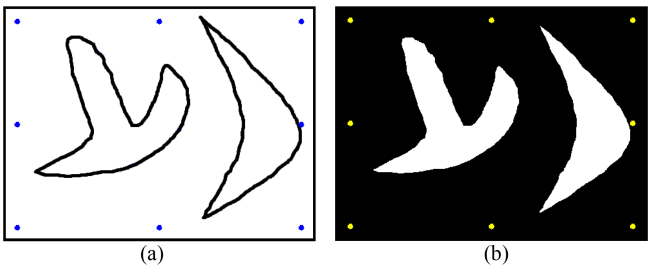

Fig. 4. The binary mask of the map and the possible locations of the cameras. (a) Field of View & Effective Range of the Camera. (b) The binary mask of the camera coverage.

Fig. 4 (a) shows the original map and (b) shows the binary mask of the map. The objects are represented by ones in the binary mask while the area of interest is represented by zeros. The possible locations of the cameras are shown in dark bule and yellow color in the original and the mask map.

A. Camera Coverage Modeling

The ideal coverage area in the two dimensional plane is bounded by the three points described in TABLE. I [7, 20].

TABLE. 1. THE POINTS THAT CONSTRUCT THE COVERAGE AREA

Point	Relative Position	Description
(x, y)	Camera Location	This point usually chosen by security expert based on the detailed study of the area of interest.
(x + r.tan (α/2), y)	Lower bound	These two points form the upper and the lower bound of the field of view, and construct with the camera location a closed polygon represents the camera coverage area.
(x - r.tan (α/2), y)	Upper bound	

Fig. 5 shows the structure of the camera field of view considering the visual angle and the visual distance. In Fig. 5 the effective range of the camera is denoted as r, the width of the camera field of view is denoted as d and the horizontal angle of the field of view denoted as α.

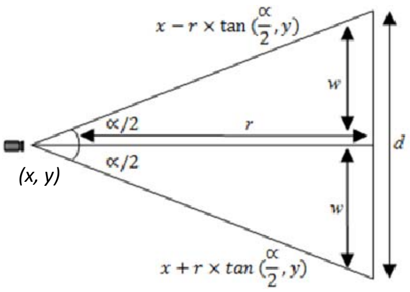

Fig. 5. The relation between the variables in the field of view and effective range formulas.

The field of view considers the area bounded by the sides of the triangle that drawn from the points described in TABLE I. The weight of the field of view for the camera under analysis is given by Eq. 6 based on the given specification of the camera.

B. The Camera Visibility

The visibility is modeled in this work through tracing the set of rays from the camera to the width of the field of view. Tracing the set of rays is achieved via implementing line drawing algorithm borrowed from the board of computer graphics techniques. The method starts by receiving the coverage area as an input to the visibility modeling stage. The Bresenham line drawing algorithm is applied to trace the coverage area line by line by starting from the camera position to the width of the field of view. The following pesudocode describes the steps of tracing the ray pixels using the Bresenham line drawing algorithm:

```
Bresenham_line(x0, x1, y0, y1)
   int deltax := x1 - x0
   int deltay := y1 - y0
   real error := 0
   real deltaerr := abs(deltay/deltax)
   int y := y0
   for x from x0 to x1
      plot(x,y)
      error := error + deltaerr
      if error ≥ 0.5 then
      y := y + 1
      error := error - 1.0
```

The visibility of each traced line is evaluated based on the pixel values contained in that line. Intersecting with the building edges represent occluding the visibility and the line is marked as invisible. The following equation describes the process of testing the set of the points in each ray against the visibility status:

$$P_{x,y} \in \begin{matrix} v \;\; if \;\; f(x,y)=1 \\ u \;\; f \;\; f(x,y)=0 \end{matrix} \tag{10}$$

Where $P_{x,y}$ is the position of the pixel in the ray, $f(x,y)$ is the intensity of the pixel v is the set of points represent the visible portion of the sensor field and u is the set of points represent the invisible pixels. The overall result is then processed through a morphological image processing step to remove the unwanted pixel values.

V. DISCUSSION

In camera placement problem, the initial set of locations is usually defined based on the knowledge of security officers and the goal is to obtain the optimized set of locations from the given set. However, camera modeling is a critical part in obtaining the optimized camera positions.

The target of our work is to model the camera coverage and visibility in highly occluded scene. Given the position and the orientation of the cameras, the proposed model is capable of calculating the coverage and visibility. The final results can be presented visually as shown in Fig. 6 and graphically as shown in Fig. 7.

TABLE. 2. CAMERA LOCATION, ORIENTATION ANGLE AND THE COVERAGE AREA

Position	Orientation angle (φ)	Coverage Area
1	225°	2300
2	270°	1600
3	315°	1651
4	360°	12
5	45°	1454
6	90°	2419
7	135°	2148
8	180°	2103

An arbitrary complex map is used to demonstrate the implementation of the model. The variation in the surrounding environment with respect to the camera position results in the variability in the measured coverage and visibility records.

Applying the model to each of the predefined camera position in the input map generates a visually different result in term of coverage area and visibility. The observed area is measured as the set of pixels included in the camera field of view of the camera. TABLE. II shows the orientation angle (φ) of the camera for each position in degrees and the corresponded the measured coverage for the same position. In contrast, Fig. 6 shows the result of a single camera simulation and the correspondence coverage.

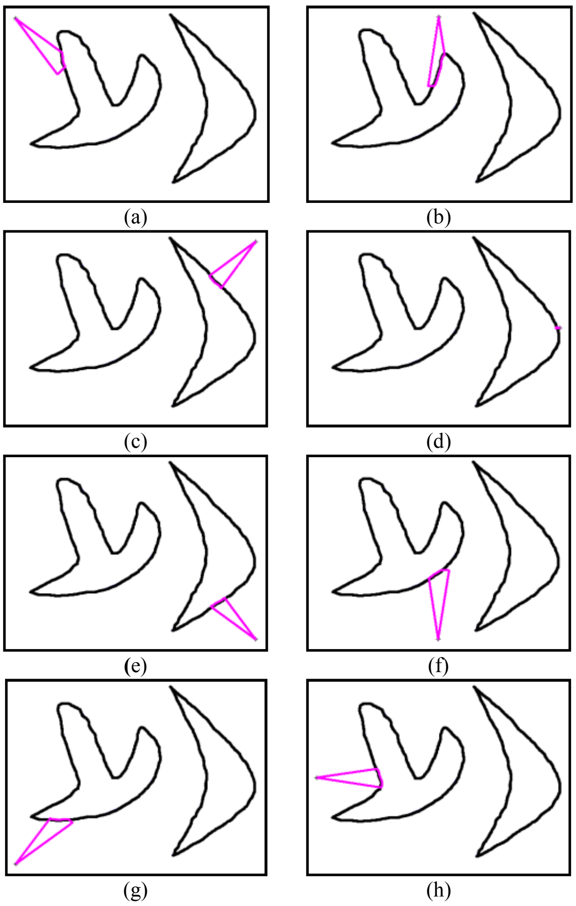

Fig. 6. Applying the proposed model, where each predefined camera position (a-h) generates a visually different result in term of coverage and visibility.

Fig. 7 shows the measured coverage achieved for the predefined camera positions. The x-axis represents the possible location of the camera and y-axis illustrates the measured coverage value per location.

VI. Conclusion

Developing a comprehensive model for demonstrating different surveillance cameras functionalities is highly required to achieve efficient planning of the current surveillance systems.

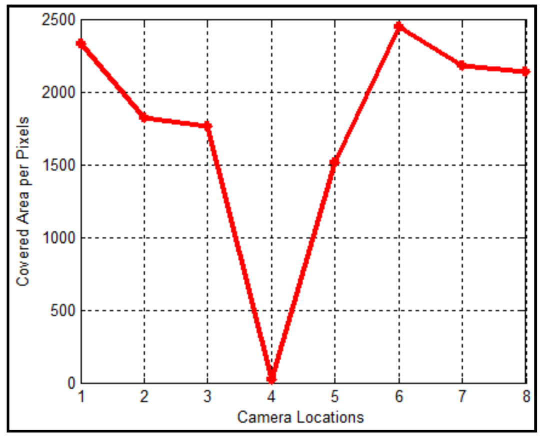

Fig. 7. Maximum Coverage with respect to the camera location.

This paper discusses in detail the visual sensor visibility and coverage for surveillance application. The visibility taxonomy in the field of computer graphics is reviewed as well as the geometric modeling of the camera.

The contribution of the paper is introducing an imagery techniques based model to simulate visual sensor behavior. The proposed model is capable of calculating the coverage area and the visibility of the sensor in complex scenarios through a flexible and effective manner. The output result of the simulation is considered promising.

The work can be extended based on the gained output for offline sensor planning, camera reconfiguration, camera calibration, camera selection and in solving the placement problem. The later problem is considered as a future direction of this work.

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