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DEPLOYMENT OF MULTIPLE VISUAL DEVICES FOR 3D SURVEILLANCE OF BIG STRUCTURE

Hyun-Lim Yang and Tai-Woo Chang*

Department of Industrial and Management Engineering
Kyonggi University
154-42 Gwanggyosan-ro, Yeongtong-gu, Suwon, Gyeonggi 16227, Korea
*Corresponding author: keenbee@kgu.ac.kr

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Abstract. *Video surveillance with CCTV is widely used for structure monitoring. As augmented reality (AR) and virtual reality (VR) technologies have come to the fore, many researches have utilized them for security and surveillance. In this study, we tried to develop a cost-efficient deployment plan of visual devices for 3D surveillance of big structure in AR and VR. In order to obtain a solution of this plan, we considered a 2-dimentional floor plan of structure and available installation area. We developed a genetic algorithm program with R.*

Keywords: 3D structure modeling, Camera placement problem, Video surveillance, Multiple device deployment, Genetic algorithm

1. **Introduction and Related Works.** With the performance improvement and growing needs for requirement of surveillance in various circumstances, video surveillance with visual devices such as closed-circuit television (CCTV) is widely used in many fields. Especially, in the case of big structures, which have high-value and have critical loss when damaged, there have been many examples using video surveillance and many researches in order to improve the performance of surveillance systems.

Conventionally, in the general circumstances of security and surveillance, they connect CCTVs directly to one-to-one corresponding display monitor. In this case, they need as many monitors as the number of cameras they have. Moreover, people have difficulty in recognizing all the situations from multiple displays simultaneously [1,2]. To solve these problems, in these days, augmented reality (AR) and virtual reality (VR) based surveillance systems have been suggested. And they make virtual models of objects and space from vision to surveil the target [2-4]. To make virtual three-dimensional (3D) models of objects or structures, we need a stereovision technique for depth perception. At least two cameras should surveil a point of object. That is, we need to record two or more images taken from different viewpoints [5].

Since the 1980s, there were many efforts to recover three-dimensional structure of objects using images [6]. Recently, many state-of-the-art techniques are developed to surveil and control the structure using 3D virtual modeling AR and VR. El-Hakim et al. [7] suggested image-based 3D modeling techniques instead of conventional laser scanning technique, and adopted it to heritage sites. And Sebe et al. [2] suggested augmented virtual environment through the 3D video surveillance. Xu and Lee [8] suggested ground detection and 3D reconstruction system with multi camera surveillance. Furthermore, many studies about vision-based 3D surveillance of structures are progressing in various fields and a large part of them have been utilized in practical situations. In this study, as an extension of the previous study [9], we consider the efficient placement problem using visual devices for 3D modeling of structure. Above all, we defined linear programming

(LP) formula. Since the camera placement problem is an NP-Hard problem, we developed a genetic algorithm (GA) program to obtain an approximate optimal solution. In addition, we used R, the open source programming language to find the solution.

In comparison with growing number of studies about 3D modeling and stereo camera calibration, few studies deal with effective camera deployment. However, for the 3D object reconstruction, camera placement is just as important as the camera performance and it decides the quality of 3D virtual models [10]. Fleishman et al. [11] considered camera placement for image modeling, but dealt within a surface, a camera, and interior surveillance. Rieffel et al. [12] suggested dynamic object tracking system simulation tool for 3D surveillance in 2D floor plan. Williams and Lee [10] also suggested camera placement simulation tool for 3D reconstruction task. Ram et al. [13] and Hörster and Lienhart [14] dealt with 2D models of camera placement problem, but they implied that it could be expanded to 3D problem.

The remainder of this paper is organized as follows. Section 2 describes the camera placement problem and proposes an LP-formulation. In Section 3, we discuss our algorithm and its experimental results. Finally, we conclude our study in Section 4.

2. **Problem Modeling.** The goal of this study is to find an efficient deployment plan of visual devices, which can cover 95% of target points for 3D surveillance of a big structure. At least two visual devices such as cameras should cover each target point. As shown in Figure 1, effective visible range R, cover angle θ, and camera direction δ are considered. Because two cameras cover black points, they can be stereo coverage points in this problem. In contrast, white points are not stereo coverage points which are covered by only a single camera. To solve the camera placement problem, we considered three types of cameras and set the objective to minimize total cost of used cameras. For modeling of structure, we make virtual spots on structure's exterior line segment at regular interval and evaluate how many spots the surveillance cameras could cover and monitor. The surveillance condition of a spot and a camera is that the spot is contained within the visible range and cover angle with specific direction and there is no obstruction on spot-camera vector.

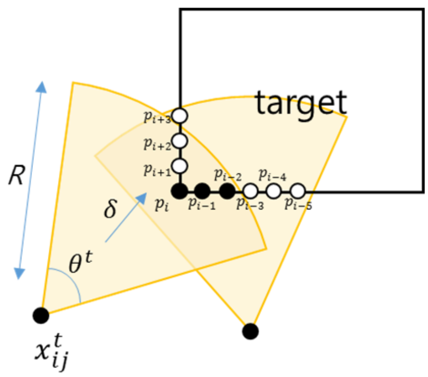

FIGURE 1. Illustration of stereo coverage of target point p_i by two cameras

2.1. **LP formulation.** Table 1 indicates the main variables used for mathematical formulating of camera placement problem for 3D modeling of structure.

We defined the decision variables as follows:

$$x^t_{ij\delta} = \begin{cases} 1 & \text{if a camera of type } t \text{ is placed at point } (i,j)\text{, with direction } \delta \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$v_{ij\delta p} = \begin{cases} 1 & \text{if two or more cameras at each point with direction } \delta \text{ cover point } p \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Table 1. Parameters used in LP formulation

Parameters	***Descriptions***
G	2-dimension of Euclidean grid
P	Set of structure target points
D	Set of orientation of the camera
T	Set of camera type
$\|P\|$	Number of target points
$\|D\|$	Number of orientations of camera
$\|T\|$	Number of camera types
R	Effective sight range of camera
c^t	Cost of a camera type t
θ^t	Cover angle of a camera type t

To determine the decision variable $v_{ij\delta p}$, we made following rules as shown in 2.2. It makes our algorithm have constraint of stereovision.

Camera placement problem can be formulated as a linear program with inequalities and many binary variables:

$$\text{Min} \quad \sum_{t\in T}\sum_{i=1}^{G_x}\sum_{j=1}^{G_y}\sum_{\delta\in D} c^t \cdot x^t_{ij\delta} \tag{3}$$

$$\text{subject to} \quad \sum_{i=1}^{G_x}\sum_{j=1}^{G_y}\sum_{\delta\in D} v^t_{ij\delta p} \cdot x^t_{ij\delta} \geq |P| \times 0.95 \tag{4}$$

$$\sum_{\delta\in D} x^t_{ij\delta} \leq 1 \tag{5}$$

$$\sum_{t\in T} x^t_{ij\delta} \leq 1 \tag{6}$$

$$\sum_{i=1}^{G_x}\sum_{j=1}^{G_y}\sum_{\delta\in D} v^t_{ij\delta} \leq |P| \tag{7}$$

The objective Function (3) means that the goal of this problem is to minimize the cost of used camera in deployment solution. The constraint (4) ensures that all the covered points should be over 95% of total target points. The constraints (5) and (6) mean that a camera can have only one direction and one type. The constraint (7) indicates that the number of possible surveillance targets is smaller than the number of total points.

2.2. **Determination of $v^t_{ij\delta p}$.** To determine $v_{ij\delta p}$ which indicate whether cameras are covering the target point or not, Range Test, Angle Test and Occlusion Test are needed. Each result of tests has logical value with TRUE or FALSE, and visibility value of the point which passed all tests will be given one, that is, $v_{ij\delta p} = 1$.

2.2.1. *Range test: $R(p)$.*

Let $\mathbb{X}$ be the matrix containing x- and y- axis value of camera placement as its first and second columns. If we consider a target point p which has (p_x, p_y), then the Range Test can be denoted as:

$$\sqrt{(x_{\cdot 1} - p_x)^2 + (x_{\cdot 2} - p_y)^2} \leq R$$

2.2.2. *Angle test:* $A(p)$.

If a camera is placed with orientation of δ which has (δ_x, δ_y), then the Angle Test can be denoted as:

$$\frac{\delta_x \times (p_x - x_{\cdot 1}) + \delta_y \times (p_y - x_{\cdot 2})}{\sqrt{\delta_x^2 + \delta_y^2} + \sqrt{(p_x - x_{\cdot 1})^2 + (p_y - x_{\cdot 2})^2}} \geq \cos(\theta^t)$$

2.2.3. *Occlusion test:* $O(p)$.

The Occlusion Test is exactly the same with what we used in previous study [9]. We can describe the concept of occlusion test as shown in Figure 2.

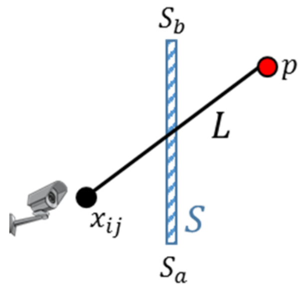

FIGURE 2. An example of an Occlusion Test

2.2.4. *Sum of visible points:* $M(i, j, \delta, p)$.

Test all the tests and calculate the covering cameras of target point p.

$$M(i, j, \delta, p) = \sum_{(i,j) \in G, \delta \in D} (R(i, j, p) \cdot A(i, j, \delta, p) \cdot O(i, j, \delta, p))$$

A target point should be covered by at least two cameras, and $v^t_{ij\delta p}$ can be determined as follows:

$$v^t_{ij\delta p} = \begin{cases} 1 & \text{if } M(i, j, \delta, p) \geq 2 \\ 0 & \text{otherwise} \end{cases}$$

3. **Algorithm and Experiments.** The camera placement problem is known as an NP-Hard problem; it requires countless sources to find exact optimal solution. To resolve this, we designed GA with R based on our LP formula, and found an approximate solution from experiments. GA is a heuristic method which performs as evolutionary computation technique to find approximate solution, and it has been utilized in many fields to deal with hard optimization problem. We designed gene of GA as 2-dimentional matrix to make it more expandable and understandable, and algorithm with considering 2-dimentional floor plan to place cameras for 3D modeling. We used R, which is specialized in statistical computing and matrix operations, to fit perfectly in our vectorized LP-formula.

For verification of our algorithm, we did our experiment on the structure having (1000×300) of available installation area. It is the same experimental design as in the previous study [9]. The goal of this problem is to find the efficient camera deployment plan around a big structure which can cover 95% of the structure. For the algorithm efficiency, all the cameras are spaced apart at least 5 meters, and target spots have 5 meters regular intervals.

As shown in Figure 3, we defined a simple floor plan of structure for experiments. Rectangle with diagonal pattern is the place where we cannot place the cameras. It is possible to put cameras to the rest of the region with regular intervals. We used a visualization program with R, which can make it easy to understand the result of algorithm.

In this study, we used three types of cameras with eight directions, and their specifications are as follows: $\{(R^t, \theta^t, c^t) | (200, 80, 10), (180, 140, 12), (160, 180, 10)\}$. For the GA

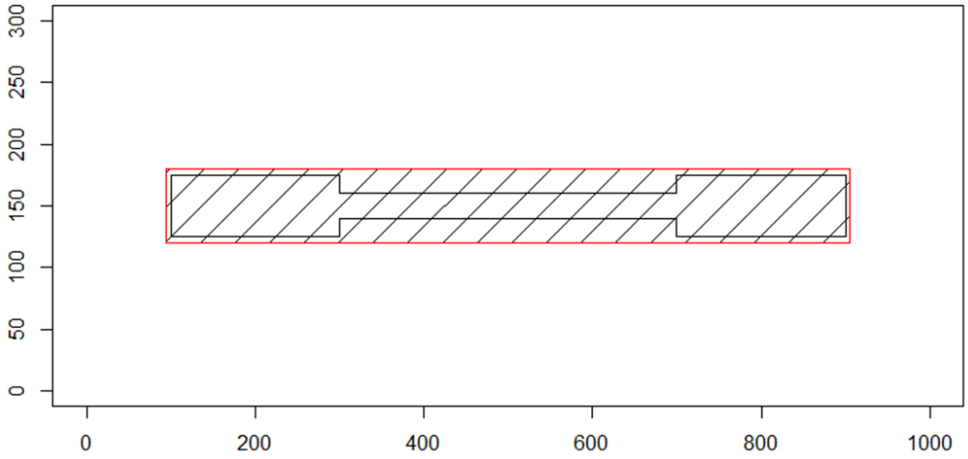

Figure 3. Two-dimensional floor plan of structure

Table 2. Best solution of the experiments

Grid	***Type***	***Direct.***	***Grid***	***Type***	***Direct.***	***Grid***	***Type***	***Direct.***
(60, 260)	3	5	(290, 290)	2	4	(380, 90)	1	2
(900, 280)	1	6	(230, 20)	1	1	(50, 230)	1	4
(210, 70)	2	1	(310, 50)	1	8	(840, 90)	3	3
(650, 190)	3	5	(850, 50)	2	1	(190, 80)	3	8
(860, 280)	1	4	(90, 170)	1	5	(350, 240)	3	5
(940, 160)	1	6	(920, 70)	2	8	(640, 270)	3	4
(800, 130)	3	2	(20, 120)	3	5	(90, 80)	2	4
(320, 80)	3	7	(490, 60)	2	1	(60, 90)	3	4
(710, 90)	3	8	(680, 70)	2	1	(990, 240)	3	6
(530, 270)	2	5	(700, 50)	2	1	(980, 170)	2	6
(900, 60)	1	5	(890, 300)	2	4	(90, 170)	2	3
(200, 190)	3	6	(130, 260)	1	7	(440, 80)	2	8
(80, 140)	1	4	(100, 230)	2	3	(160, 270)	1	6

parameters, population is 30, generation is 500, crossover rate is 0.80, and mutation rate is 0.1. To make solution take results that are more diverse and have rapid convergence, 4 selections and twice crossover operations were used. We used a roulette wheel selection, and made a totally new solution if random uniform number between 0 and 1 is lower than mutation rate.

After the 500 generations of GA, we found a near-optimal solution of efficient camera deployment as shown in Table 2. To cover 98.764% parts of the structure, 39 cameras are used, and it costs 418. To sum up the result, 12 of type 1 cameras, 14 of type 2 cameras, and 13 of type 3 cameras are used.

Figure 4 indicates the positions and directions of the cameras. Most target points are surveilled by at least two visual devices each, with 39 cameras. Fewer cameras were placed on the north and south flat-sides of structure rather than on the other angled-side of structure. It is not much different from our conceptual inference, in which more cameras will be needed to surveil the irregular side of structure. However, we could find a few redundant cameras, such as marked (*) ones in the lower-left corner. It comes from a limitation of GA, and two hypotheses are possible: bad schemas were preserved through whole generation, or bad solutions were generated by mutation operations.

4. **Conclusions and Future Research.** In time, the market of AR and VR is getting larger and larger. In addition, there are many attempts to do safety management using

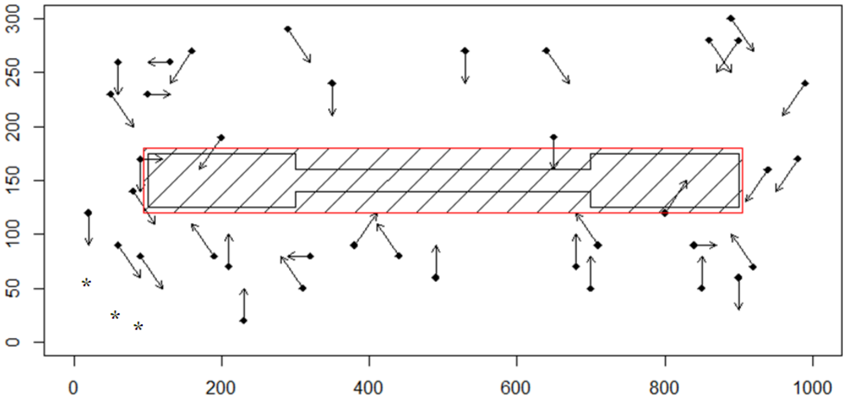

Figure 4. Experimental result of camera placement

those state-of-art techniques. Besides, it is difficult to sense the vision with multiple deployed cameras for 3D surveillance, especially in the case of large structure, and critical issue to maintain lots of installed cameras. It is possible to formulate the LP model, but it is an NP-hard problem, very hard to find an optimal solution in multi-type cameras.

In this study, we defined LP formula of camera placement problem especially for the 3D structure modeling, and represented a GA with R. From our program with the algorithm, we could find a near-optimal feasible solution using suggested GA and deployment solution which can make real 3D model of structure (over coverage 95%) with the placement rule.

However, there are still some limitations. There were a few redundant cameras in our placement rule, owing to the GA procedure. In addition, it was too confused to display all of visible areas of each camera as fan-shape. In future research, we plan to make our algorithm have more high-performance with new techniques of preserving elite solutions. Also, we need to delve into the question how we can display our solutions efficiently.

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