Optimal Camera Placement based Resolution Requirements for Surveillance Applications

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Keywords: Camera Network Placement, PTZ Cameras, Static Cameras, Binary Integer Programming Algorithm, Camera Resolution.

Abstract: In this paper, we focus on the problem of optimally placing a mixture of static and PTZ cameras based on the resolution requirement, this configuration will be useful later cameras planning. The static cameras used for detecting an object or an event, this result is used to select the best PTZ camera within the network to identify or recognize this moving object or event. In our work the monitoring area is represented by a grid of points distributed uniformly or randomly (S. Thrun, 2002), then using surface-projected monitoring area and camera sensing model we develop a binary integer programming algorithm. The results of the algorithm are applied successfully to a variety of simulated scenarios.

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1 INTRODUCTION

The terrorism upsurge, open conflicts and social faintness etc., spread more and more in this age. The priorities of the international community turn to the protection of the goods and people, which lead the field of video surveillance to be one of the actual research importance. Video surveillance is a need in many applications as monitoring a production plant, an area for security reasons, industrial products etc. Suitable placement of visual sensors is an important issue, as these systems demand maximizing coverage of essential area with minimum number of cameras, which imply minimum cost and good quality of service. The best quality of acquired images depend on the position and orientation of the cameras.

In video surveillance application, it is required to cover a monitoring area for different tasks requirement, thus it is necessary to place a set of cameras in order to detect, recognize and identify specific events such as people, equipment, extraneous objects, etc. One of the fundamental challenge when we deploy a network of cameras is coverage with different resolution tasks in addition to others as deployment, the appropriate location calculation and tracking.

The main goal of this work is to improve the off-line camera placement for surveillance applications, considering the camera placement problem based on Resolution requirements. Camera placement depends on the allowed location of cameras, obstacles present in sensitive areas, and the essential zones that have the priority in a monitoring area. Hence the placement problem becomes an optimization problem with inter related and competing constraints. Our goal is to determine how to place a mixture of fixed and Pan-Tilt-Zoom cameras in optimal manner. In this way, we aim to provide the ability to guarantee the tree tasks requirement in one monitoring area that are detection, recognition and identification .The role of detecting an event is done by the static cameras, and this later send a signal to the appropriate PTZ cameras to identify or recognize according to the task needed.

Further still, a mixture of both fixed and PTZ cameras are convenient for several scenario because the overall cost could be reduced not only for detection resolution but also for identification and recognition tasks. In the next section, we review some of the work related to our problem. Then, in section 3, we present the fundamental methodology used in our solution. Next, in section 4, we describe the results of the algorithm applied to a variety of simulated scenarios. Finally, in section 5, we conclude giving hints on possible future lines of research.

Bettahar H., Morsly Y. and Djouadi M..
Optimal Camera Placement based Resolution Requirements for Surveillance Applications .
DOI: 10.5220/0005046302520258
In *Proceedings of the 11th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2014), pages 252-258
ISBN: 978-989-758-039-0

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2 WORK BACKGROUND

The increasing tendency in surveillance and guarding in many smart areas give grow of many problems in camera placement and coverage (J. Wangand and N. Zhong, 2006). For example, in Computational Geometry, large progress has been done in solving the problem of "optimal guard location" for a polygonal area, e.g., the Art Gallery Problem(AGP), where the assignment is to determine a minimal number of guards and their fixed positions, for which all points in a polygon are monitored (J. Urrutia, 2000).

After, a large study has been devoted on the problem of cameras optimal placement to obtain complete coverage for a given area. For instance, Hörster and Lienhart (R. Lienhart and E. Horster, 2006) focus on maximizing coverage with respect to a predefined "sampling rate" which guarantee that an object in the area will be observed at a certain minimum resolution. Although, their camera type does not have a circular sensing ranges, i.e., they work with a triangular sensing range. In (K. Chakrabarty, H. Qi, and E. Cho, 2002), (S. S. Dhillon and K. Chakrabarty, 2003), the environment is modelled by a grid map. The authors compute the camera placement in such a way that the desired coverage is accomplished and the overall cost is minimized. The cameras are placed on a grid cell such that each of them is covered by at minimum one camera. Also, Murat and Sclaroff (U. Murat and S. Sclaroff, 2006) modelled three types of cameras: Fixed perspective, Pan-Tilt-Zoom and Omnidirectional. However, they use only one type of camera at one time. Dunn and Olague (E. Dunn, G. Olague, and E. Lutton, 2006) consider the problem of optimal camera placement for exact 3D measurement of parts Located at the center of view of several cameras. They demonstrate good results in simulation for known fixed objects. In (X. Chen and J. Davis, 2000) , Chen and Davis develop a resolution metric for camera placement considering the occlusions. In (S. Chen and Y. Li , 2004), Chen and Li describe a camera placement graph utilizing a genetic algorithm approach. Our work is oriented in the same direction as those presented above. However, in our research, we consider the simultaneous use of both fixed and PTZ cameras in one monitoring space. We do optimal static camera placement for detection task and optimal PTZ camera placement for to guarantee the identification and recognition requirements.

3 MULTI-CAMERA PLACEMENT PROBLEM

Our objective is to find out the optimal position, orientation and the minimum number of fixed cameras to cover a specific area for detection requirements, after find out the optimal position, orientation and the minimum number of PTZ cameras to cover the same detected area for identification and recognition requirements. This is a typical optimization problem where some Constraints are given by the characteristics of both the camera (field of view, focal length) and the environment (size, shape, obstacle and essential zones). In our approach, the step of minimization is done based on linear integer programming method (S. S. Dhillon and K. Chakrabarty, 2003), (E. Horster and R. Lienhart, 2006). To identify the spatial representation of the environment, we use a Grid of points (S. Thrun, 2002).

This work assumes that both the sensing model and the environment are surface-projected defining two-dimensional models. We model the static camera field of view by an isosceles triangle as shown in Fig. 1, where its working distance is calculated based on the detection resolution requirements and we model the surface-projected PTZ camera field of view using also isosceles triangle taken into consideration the extended FOV due to motion which in our case $360°(2\pi)$,by dividing its total FOV in to sectors ,each sector represent one resolution task based on the identification or recognition resolution value taking into consideration the zoom effect as shown in fig(3,4),which is caused by the zoom lenses, this later often described by the ratio of their longest to shortest focal lengths. For instance, a zoom lens with focal lengths from 100mm to 400mm may be described as a 4:1 or "4X" zoom. That is, the zoom level of a visual sensor is directly proportional to its focal length.

3.1 Static Camera

We denote the discretized sensors space as $(S_i, i = 1,2,\ldots,N)$ to be deployed in a given area, which is approximated by a polygon A. In our labour, we focus on polygon discretized fields. For each deployed sensor S_i, we know its location (X_{S_i}, Y_{S_i}) in the 2-D space as well as its orientation parameters required to model the static camera Field of View (FOV). We have modelled the FOV $\exists_i$as done in (Morsly, Y ; Aouf, N ; Djouadi, M.S and

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Richardson, M. t, 2012), (R. Lienhart and E. Horster, 2006) using an isosceles triangle as shown in Figure 1.

For each sensor S_i, the parameter φ is the horizontal angle to the bisection of the FoV angle, which defines the pose of the camera. α is the FoV vertex angle, which defines the aperture of the camera and ω_d defines the working distance of the sensor. Fig. 2 describes the relationship between the fundamental parameters of a sensor imaging system. The parameters of the triangle, in Figure 1, are calculated, given the camera intrinsic parameters and the desired viewing resolution.

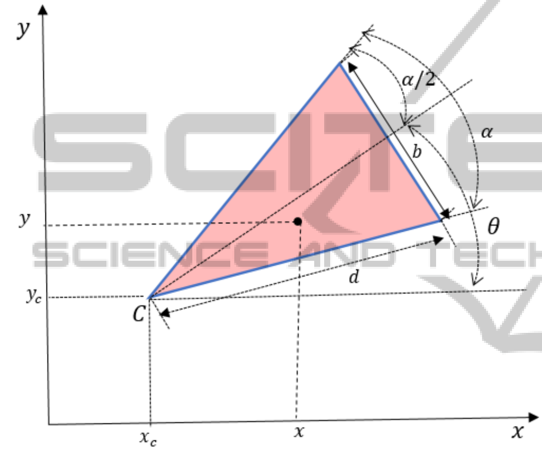

Figure 1: Field-of-view $\exists_i$of sensor C_i in 2-D space.

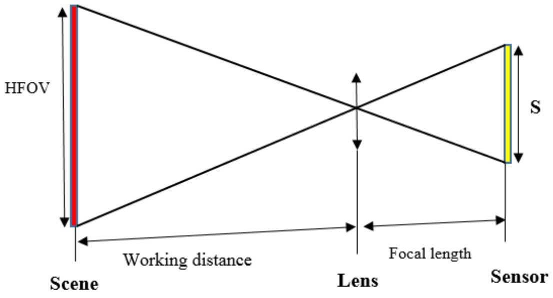

Figure 2: Fundamental parameters of an imaging system.

Getting the FoV by a triangle allows describing the area covered by each camera C_i, positioned at (X_{C_i}, Y_{C_i}) and orientation φ ,with three linear constraints:

$$\cos(\theta).(x - X_{C_i}) + \sin(\theta).(y - Y_{C_i}) \le d \qquad (1)$$

$$sin(\theta).(x - X_{C_i}) + cos(\theta).(y - Y_{C_i}) \le \frac{b}{2.d} .\left(cos(\theta).(x - X_{C_i}) + sin\,\theta.(y - Y_{C_i})\right) \qquad (2)$$

$$-sin\,\theta.(x - X_{C_i}) + cos(\theta).(y - Y_{C_i}) \le -\frac{b}{2.d} .\left(cos(\theta).(x - X_{C_i}) + sin\,\theta.(y - Y_{C_i})\right) \qquad (3)$$

Thus, each point (x, y) of the discretized monitoring area can be observed by a camera C_i if the three constraints (1), (2) and (3) are satisfied.

Theoretically, sensors can be placed anywhere in the monitoring space since the sensor variables X_{C_i}, Y_{C_i} and θ are continuous variables. Practically, an approximation of the monitoring space by a two-dimensional grid of points allows solving the formulated optimization problem in discrete representation .The distance between two grid points in the x and y directions is determined by the spatial sampling frequencies:

$$f_x, f_y : w_x = 1/f_x \,;\, w_y = 1/f_y \qquad (4)$$

Thus, cameras are constrained to be positioned only at these discrete grid points, and coverage is guaranteed relative to these grid points. The problem becomes, then, a grid coverage problem.

So, given a discretized monitoring area and only one type of camera, our problem is to find an assignment of sensors to the grid of points such that every point is covered by at least one sensor. Once we defined the problem, visibility and environment models, we solve it by defining the fitness function and constraints as follows. Firstly, the fitness function is to find the minimum number of cameras to maximize the coverage.

$$Min \sum_{\theta=1}^{f\theta} \sum_{i_1=1}^{fx} \sum_{j_1=1}^{fy} C_{i_1,j_1,\theta} \qquad (5)$$

Subject to

$$\sum_{\theta=1}^{f\theta} \sum_{i_1=1}^{fx} \sum_{j_1=1}^{fy} C_{i_1,j_1,\theta}\, Acp(i_1, j_1, \theta_1, i_2, j_2) \ge M$$

$$1 \le i_2 \le f_{x2},\ 1 \le j_2 \le f_{y2} \qquad (6)$$

$$\sum_{\theta=1}^{f\theta} C_{i_1,j_1,\theta} \le 1$$

$$1 \le i_1 \le f_{x1} ,\, 1 \le j_1 \le f_{y1} \qquad (7)$$

Equation (6) guarantee that each grid point of the monitoring space is covered by at least one camera and equation (7) to ensure that only one camera can be placed on each grid point.

In the case of different types of cameras such as cameras with different working distances which means different resolutions and optics (i.e., focal

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lengths), the camera placement problem is similar to the problem treated above. In this case, the goal is to find the arrangement and the number of cameras with different FoV parameters that minimize the total cost while ensuring coverage. This optimization problem is formulated as follows:

$$G = \sum_{nc=1}^{NC} K_{nc} \left(\sum_{\theta=1}^{f_\theta} \sum_{i_1=1}^{f_x} \sum_{j_1=1}^{f_y} C_{i_1,j_1,\theta,\mathrm{nc}} \right) \quad (8)$$

Subject to

$$\sum_{nc=1}^{NC} \sum_{\theta=1}^{f_\theta} \sum_{i_1=1}^{f_x} \sum_{j_1=1}^{f_y} C_{i_1,j_1,\theta,\mathrm{nc}} A_{cp}^{nc}(i_1, j_1, \theta_1, i_2, j_2) \geq 1 \quad (9)$$

Where NC is the total number of cameras and K_{nc} is the individual cost of each camera.

To insure that at each grid point only one camera can be placed, we add the constraint below:

$$\sum_{nc=1}^{NC} \sum_{\theta=1}^{f_\theta} C_{i_1,j_1,\theta,nc} \leq 1\,, \quad (10)$$

$$1 \leq i \leq f_x\,, 1 \leq j \leq f_y$$

Where the binary variable $C_{i_1,j_1,\varphi}$ define whether there is a camera in a grid point (i,j). It is defined as

$$C_{i_1,j_1,\theta} = \begin{cases} 1 & \text{If a camera is positioned at grid point } (i,j) \text{ with orientation } \theta \\ 0 & \text{Otherwise} \end{cases} \quad (11)$$

We define a binary variable Acp to refer to the points viewed by the different cameras in the 2-D space.

$$Acp(i_1, j_1, \theta_1, i_2, j_2) = \begin{cases} 1 & \text{If a camera positioned at grid point } (\mathrm{i}_1, \mathrm{j}_1) \text{ with orientation } \theta \text{ cover grid point } (\mathrm{i}_2, \mathrm{j}_2) \\ 0 & \text{Otherwise} \end{cases} \quad (12)$$

3.2 PTZ Camera

Our surface-projected PTZ camera model is shown in figure 3. Based on the resolution requirements we have modelled the PTZ camera .We have modelled identification ,recognition and monitoring visualization zones considering the resolution needed for each task, which is used to calculate each working distance for each visualization zone using equations(13,14).

$$Hfov = \frac{number\_pixel\_horizontal}{resolution\_number} \quad (13)$$

$$Camer\_dist = \frac{Hfov * focal\_len}{chip\_width} \quad (14)$$

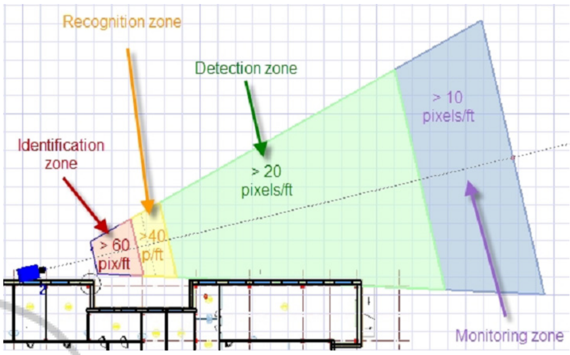

Figure 3: Surface-projected PTZ camera model based resolution requirement.

The Figure. 4 represents the camera field of view projected to the ground. The point (x_s, y_s) corresponds to the camera position in the ground, the working distances w_i, w_r corresponds to the identification and recognition resolution respectively and w_{iz}, w_{rz} corresponds to the identification and recognition resolution respectively after zoom effect and φ the orientation with respect to the x axis, α is the FoV vertex angle.it is assumed that the PTZ camera has 360° the extended field of view due to motion.

To ensure that each grid point is identified which ensure automatically the recognition task, it is necessary to satisfy the two constraints:

$$\sqrt{\begin{matrix}(cos(\varphi).(x - X_{S_i}) + sin\,\varphi\,.(\mathrm{y} - Y_{S_i}))^2 + \\ ((-sin\,\varphi).(x - X_{S_i}) + cos(\varphi).(\mathrm{y} - Y_{S_i}))^2\end{matrix}} \leq w_{iz} \quad (15)$$

$$(cos(\varphi).(x - X_{S_i}) + sin\,\varphi\,.(\mathrm{y} - Y_{S_i})) \geq 0 \quad (16)$$

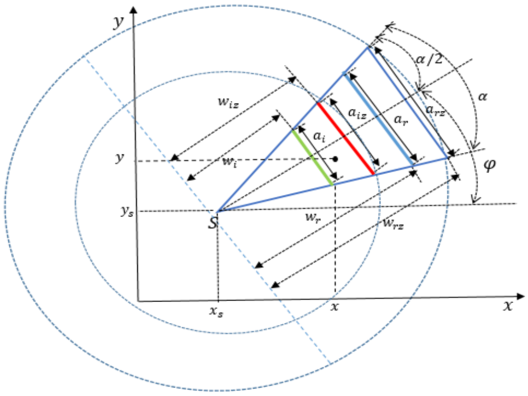

Figure 4: Surface-projected PTZ camera model based resolution requirement.

With this information, we compute the

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assignment of cameras to grid points such that every point is covered by at least one camera and the coverage is maximized.

The objective function is to find the minimum number of sensors to maximize the coverage given a PTZ camera model, as

$$Min \sum_{\varphi=1}^{f_\varphi} \sum_{i_1=1}^{f_x} \sum_{j_1=1}^{f_y} Sptz_{i_1,j_1,\varphi} \tag{17}$$

Subject to

$$\sum_{\varphi=1}^{f_\varphi} \sum_{i_1=1}^{f_x} \sum_{j_1=1}^{f_y} Sptz_{i_1,j_1,\varphi}\, Acp(i_1,j_1,\varphi_1,i_2,j_2) \geq M$$

$$1 \leq i_2 \leq f_{x2},\ 1 \leq j_2 \leq f_{y2} \tag{18}$$

$$\sum_{\varphi=1}^{f_\varphi} Sptz_{i_1,j_1,\varphi} \leq 1$$

$$1 \leq i_1 \ \leq f_{x1} \tag{19}$$

Equations (18) ensure that each grid point of the monitoring space is identified by at least one camera and equation (19) to ensure that camera has to be located on a grid point. and only one camera can be placed on each grid point.

Where the binary variable $Sptz_{i_1 j_1,\varphi}$ represents whether there is a PTZ camera in a point (i,j) . It is defined as:

$$Sptz_{i_1,j_1,\varphi} = \begin{cases} 1 & \text{If a camera is positioned at grid} \\ & \text{point } (i,j) \text{ with orientation } \varphi \\ 0 & \text{Otherwise} \end{cases} \tag{20}$$

4 RESULTS

We show some results obtained using binary integer programming algorithm in 2-D case.

We considered the case of one type of cameras Figure 5. Then, two types of cameras Figure 6 where a cost of 120 $ was assigned for the camera with the larger FoV while only 80 $ was assigned for the camera with the smaller FoV.

After we took in consideration the case of presence of obstacles and essential zone which is denoted as a critical and important zone which need more attention at the time of monitoring operation using two type of cameras Figure 7, Figure 9.

In all figures, bold blue lines represent the borders of the area to be covered while the light lines represent the area grid. The grid nodes to be covered are the intersections points of these later lines. The static camera's FoV are represented by triangles with dotted red lines in the case of only type of cameras ,in the case of two types ,the second type represented by a green dotted lines .The PTZ cameras' FOV are presented by a red triangles showing the different working distances for the different resolution requirements and the extended FOV due to motion by a circler blue lines .The green small squares represent the optimal position of the cameras to be deployed for the placement ,the obstacles is represented by a bold blue polygonal and the essential zone by black rectangle .

4.1 Static Camera

In these subsection we took the four cases: one type of cameras, different types of cameras, presence of obstacles and the case of presence of essential zones.

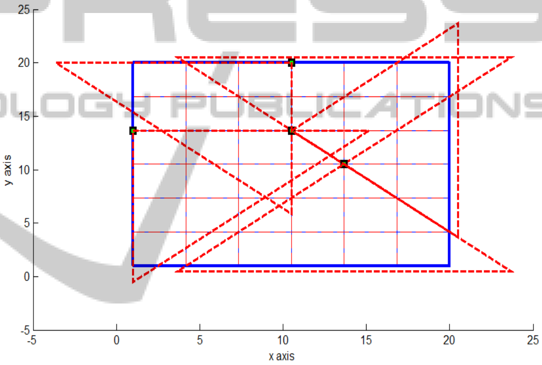

Figure 5: Optimal placement of static cameras. (1 type of camera,$w_d = 10\,m, f_x = 6, f_y = 6, f_\theta = 8, \alpha = 90°$).

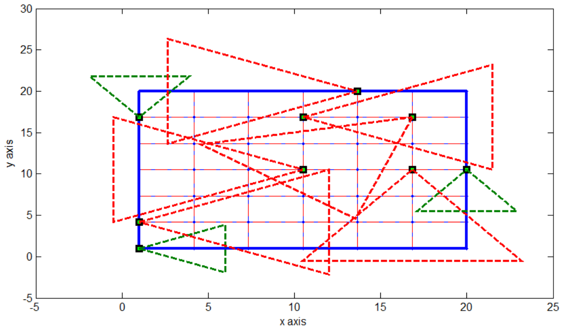

Figure 6: Optimal placement of static cameras. (2 type of camera,$w_{d1} = 10\,m, w_{d2} = 4\,m, f_x = 6, f_y = 6, f_\theta = 8, \alpha = 60°$).

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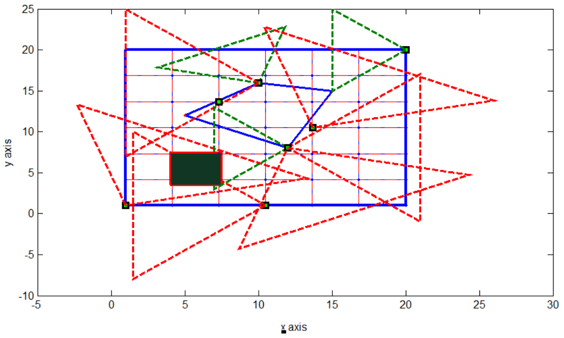

Figure 7: Optimal placement of static cameras considering the presence of obstacle and essential zone. (2 type of camera, $w_{d1} = 10\,m, w_{d2} = 4\,m, f_x = 6, f_y = 6, f_\theta = 8, \alpha = 60°$).

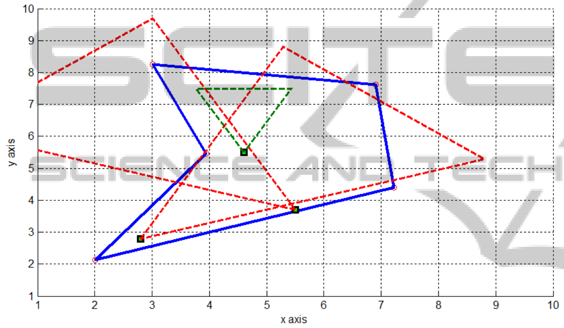

Figure 8: Optimal placement of static cameras for complex shape of monitoring area (2 type of camera, $w_{d1} = 10\,m, w_{d2} = 4\,m, f_x = 6, f_y\ 6, f_\theta 8\ , \alpha\ = 60°$).

4.2 PTZ Camera

For the simulation of a static cameras, we considered the same monitoring area dimensions for figure 9 without with presence of obstacles and essential zones, and in figure 10 we considered them.

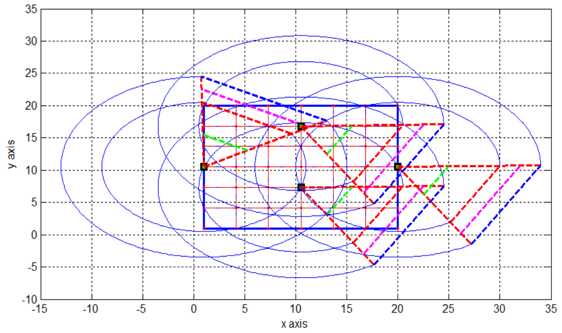

Figure 9: Optimal placement of PTZ cameras. ($w_i = 4\,m, w_{iz} = 6\,m, w_r = 8\,m, w_{rz} = 10\,m, f_x = 6, f_y = 6, f_\varphi = 8, \alpha = 60°$).

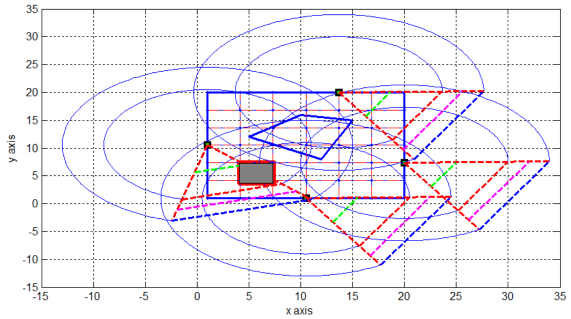

Figure 10: Optimal placement of PTZ cameras considering the presence of obstacle and essential zone.. ($w_i = 4\,m, w_{iz} = 6\,m, w_r = 8\,m, w_{rz} = 10\,m, f_x = 6, f_y = 6, f_\varphi = 8, \alpha = 60°$).

4.3 Static and PTZ Camera

For the simulation of mixtures of static and PTZ cameras, we considered the same monitoring area dimensions with and without presence of obstacles and essential zones.

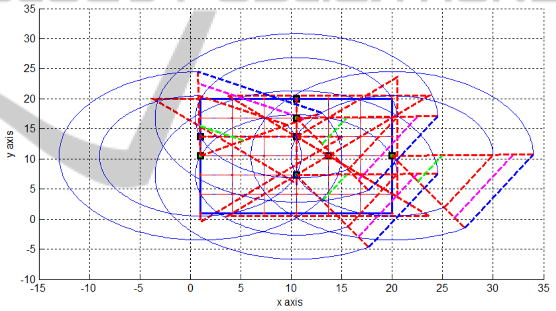

Figure 11: Optimal placement of static and PTZ cameras. ($w_i = 4\,m, w_{iz} = 6\,m, w_r = 8\,m, w_{rz} = 10\,m, f_x = 6, f_y = 6, f_\theta = f_\varphi = 8, \alpha = 60°$).

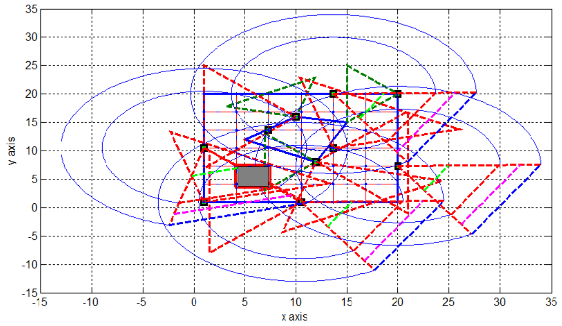

Figure 12: Optimal placement of static and PTZ cameras with presence obstacles and essential zones. ($w_i = 4\,m, w_{iz} = 6\,m, w_r = 8\,m, w_{rz} = 10\,m, f_x = 6, f_y = 6, f_\theta = f_\varphi = 8, \alpha = 60°$).

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5 CONCLUSION

We have formulated an optimization problem on camera placement based on a mixture of static and PTZ cameras, where a minimum number of them are spread out to provide a maximized coverage of the monitoring area. The use of a combination of static and PTZ cameras demonstrate functional to outlook such as reduction in costs and information processing. This is, because the PTZ camera can monitor larger areas with every snapshot due to its resolution capacity and extended FOV due to motion.

Several interesting issues arise when one applies our algorithm to a real situation. For instance, fixed cameras are not able to recognize and identify objects, because their resolution is limited, but they are capable of detecting moving objects and this result can be used to select the best PTZ camera within the network to identify and recognize the moving object

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