Camera Placement in Smart Cities for Maximizing Weighted Coverage With Budget Limit

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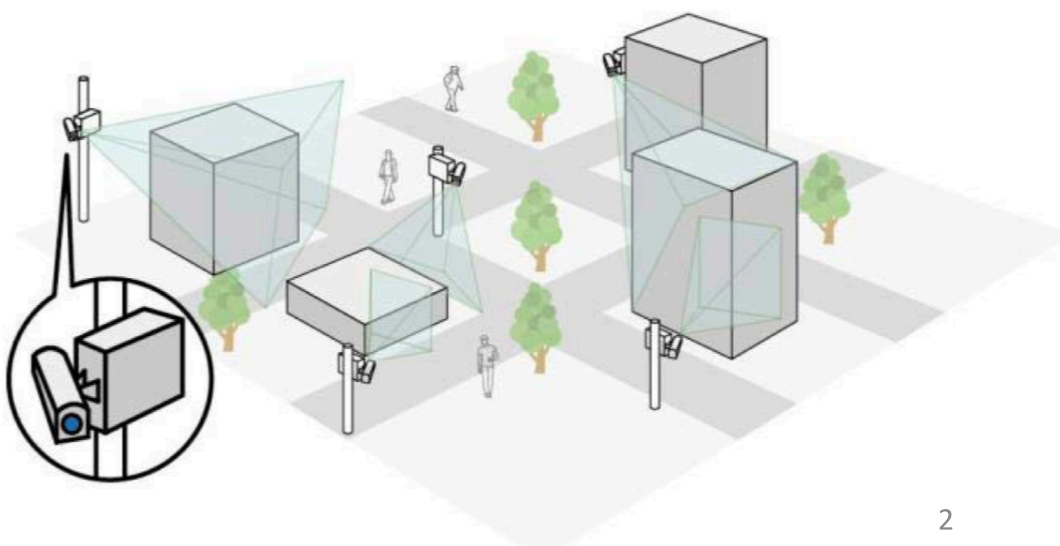
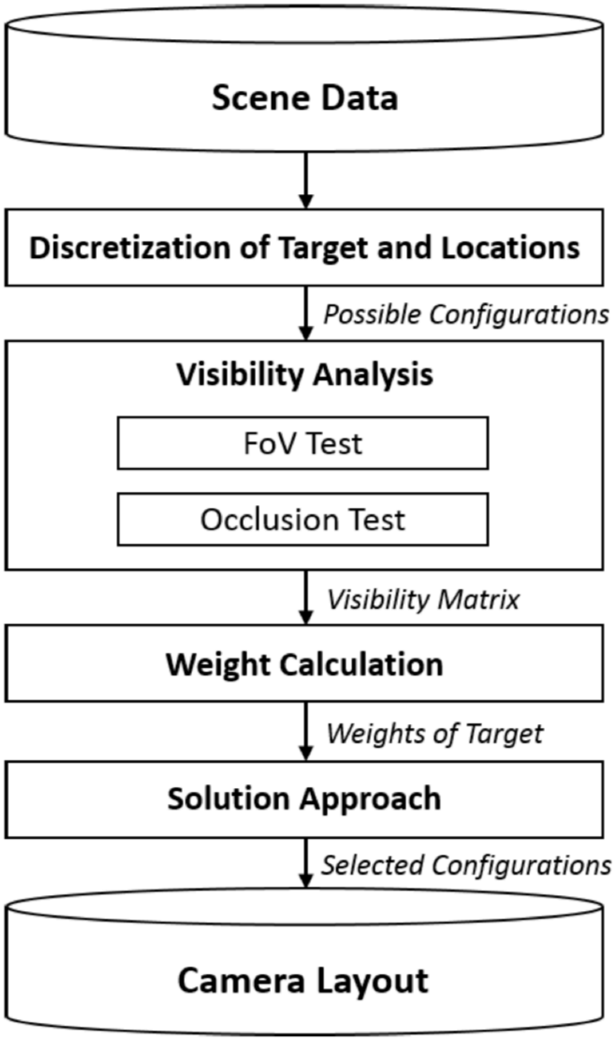
Introduction

- Video surveillance systems incorporating wireless camera networks have played significant roles in the management of core infrastructures.
- This paper address the camera placement problem for minimization of weighted coverage under a budget limitation in a 3D environment.
- They develop a heuristic algorithm.



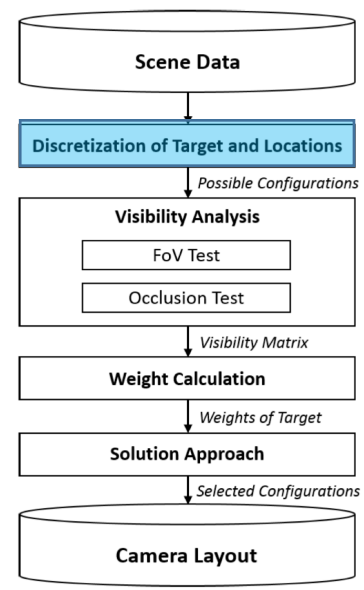
Collaboration-based Local Search Algorithm (COLSA)



- Framework for solving camera placement problem

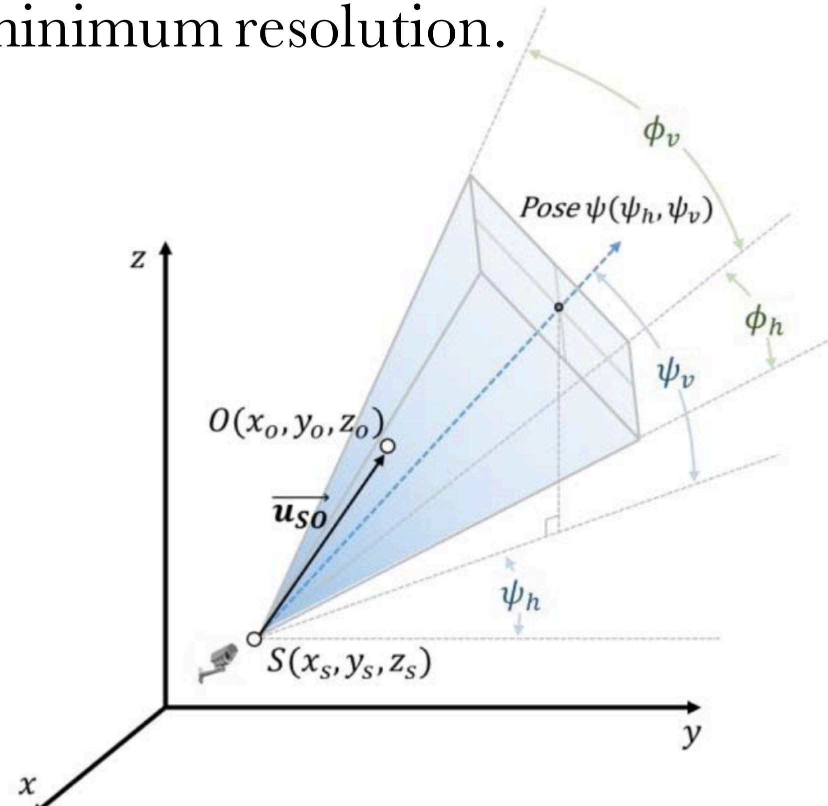
Collaboration-based Local Search Algorithm (COLSA)

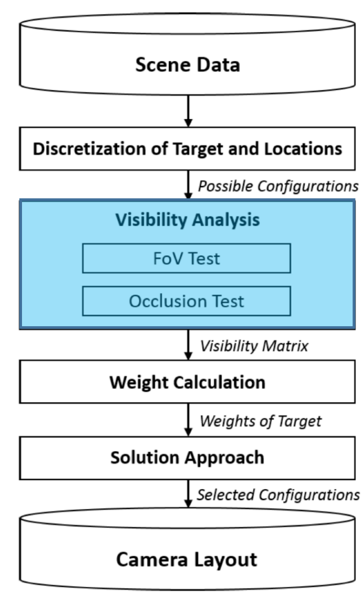
- Discretization of Target and Location
  - Discretization of the the target and camera locations into 3D grid points
  - To reduce the computation time of the entire methodology
  - The computation time of visibility analysis is inversely proportional to the grid size



Collaboration-based Local Search Algorithm (COLSA)

- Field of View Test
  - The FoV area calculate between working distance, horizontal and vertical viewing angle, and the pose.
  - The working distance and the camera viewing angle can be required minimum resolution.





Collaboration-based Local Search Algorithm (COLSA)

- Field of View Test
  - Confirm whether a camera position *s* can cover a target point *o*. The constrain shows as follow:

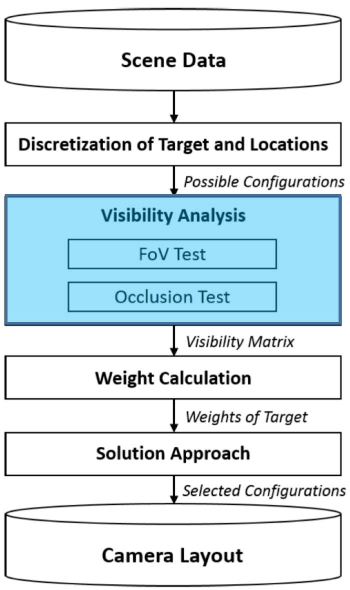
$$\overrightarrow{u_{so}} = \overrightarrow{o} - \overrightarrow{s}$$

$$\psi_h - \frac{\phi_h}{2} \leq \arctan\left(\frac{x_o - x_s}{y_o - y_s}\right) \leq \psi_h + \frac{\phi_h}{2}$$

$$\psi_v - \frac{\phi_v}{2} \leq \arcsin\left(\frac{z_o - z_s}{\left\|\overrightarrow{u_{so}}\right\|}\right) \leq \psi_v + \frac{\phi_v}{2}$$

$$\left\|\overrightarrow{u_{so}}\right\| \leq d$$

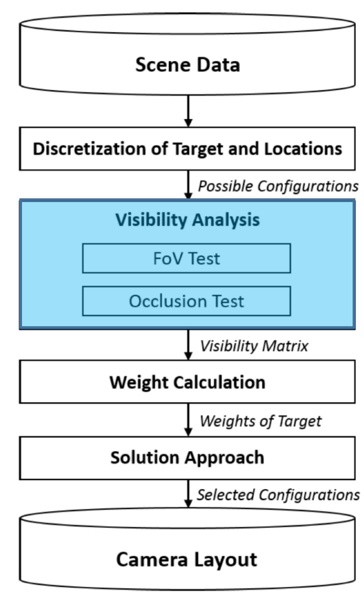
o: target point, s: camera position, ψ : pose



Collaboration-based Local Search Algorithm (COLSA)

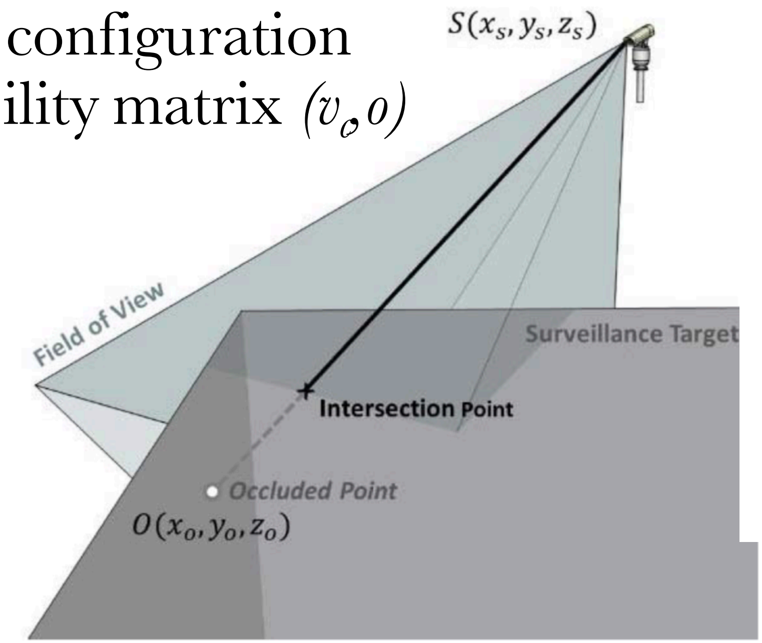
- Field of View Test
  - Select three different types of camera and calculate the working distance.

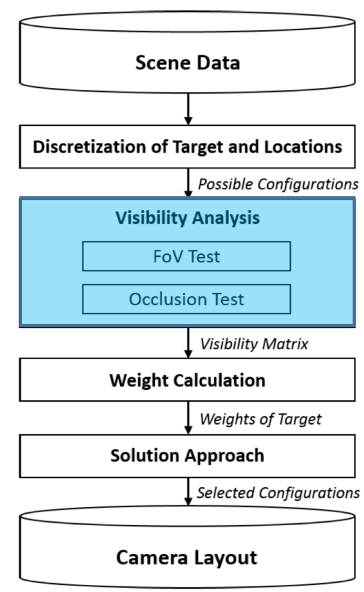
Camera Types	A	B	C
Vertical Angle (ϕ_v)	51.45	60.95	60.62
Horizontal Angle (ϕ_h)	93.91	105.19	104.82
Working distance with zooming (d) (meters)	27.5	15	11.3
Price (USD)	1085	429	379



Collaboration-based Local Search Algorithm (COLSA)

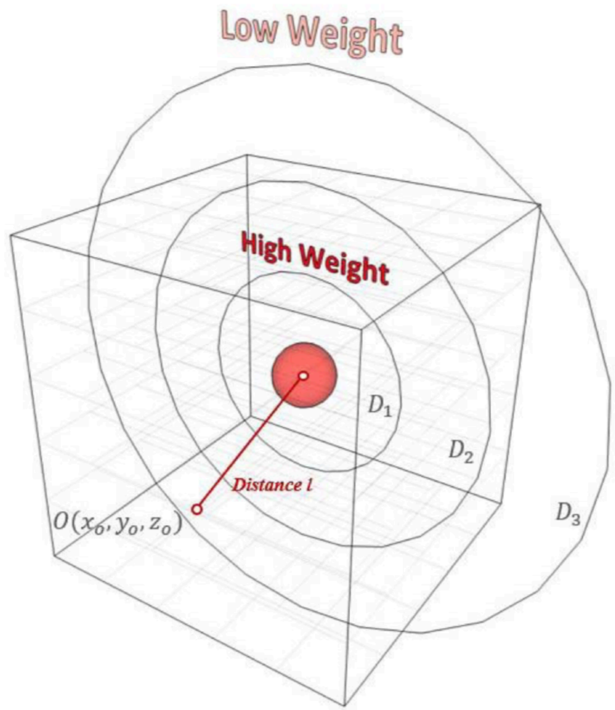
- Occlusion Test
  - The gray dotted line in the following figure represents the invisible area occluded by the plane of a surveillance target itself.
- Visibility Analysis
  - A Candidate Camera Configuration: position, camera type, azimuth, elevation
  - Candidate camera configuration is saved in the visibility matrix (v_c, o)

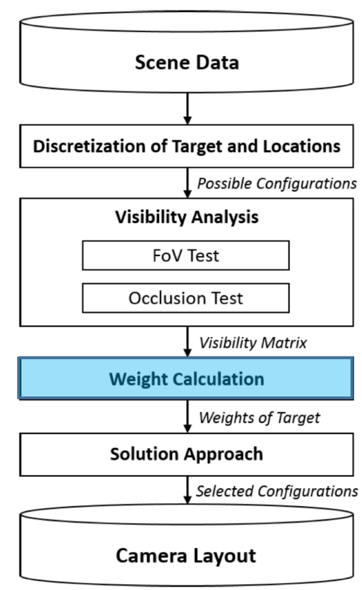




Collaboration-based Local Search Algorithm (COLSA)

$$w_o = \begin{cases} 3 & (if\ \ l < D_1) \\ 2 & (if\ \ D_1 \le l < D_2) \\ 1 & (if\ \ D_2 \le l) \end{cases}$$





$$R(\%) = \frac{\sum_{o \in O} w_o \times y_o}{\sum_{o \in O} w_o} \times 100$$

R: weighted coverage rate,

y_0 =1 , the target point is coverage

y_0 = 0, the target point is not coverage

Collaboration-based Local Search Algorithm (COLSA)

- Mathematical Representation

$$\text{maximize} \sum_{o \in O} w_o \cdot y_o / \sum_{o \in O} w_o$$

$$\text{subject to} \quad \sum_{(s, j_s) \in V_o} c_s \cdot x_{s,j_s} \leq B$$

$$\sum_{(s, j_s) \in V_o} x_{s,j_s} \geq y_o$$

$$\sum_{j_s} x_{s,j_s} = 1 \quad \forall s \in S$$

$$x_{s,j_s} \in \{0, 1\} \quad \forall s \in S$$

$$y_o \in \{0, 1\} \quad \forall o \in O$$

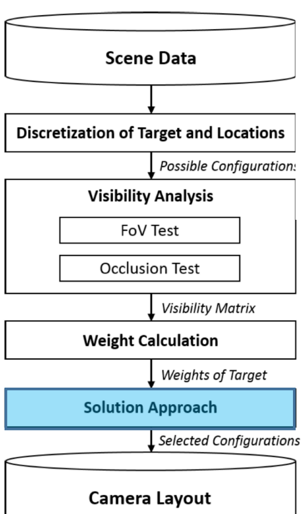
Indices	s	Index of cameras, $s \in S$
	o	Index of target points, $o \in O$
	j_s	Index of configurations of camera s
Parameters	w_o	Weight of target points
	c_s	Cost of cameras
	B	Budget Limitation
Set	V_o	Cameras and their configurations that cover target point o
Decision Variables	y_o	If a target point o is covered by the selected camera configurations, y_o = 1; otherwise, y_o = 0.
	x_{s,j_s}	If a configuration j_s is chosen for camera s, x_{s,j_s} = 1; otherwise, x_{s,j_s} = 0.

Collaboration-based Local Search Algorithm (COLSA)

1. Calculate the c_o
2. Calculate the cr_s
3. Select the c' with highest cr_s until reach the budget limit

$$c_o = \frac{n_c - \sum_{c \in C} v_{c,o}}{n_c} \times \prod_{c \in C'} (1 - v_{c,o})$$

$$cr_c = \frac{\sum_{o \in O} (w_o \cdot c_o)}{K_c}$$



Algorithm 1 Collaborative Allocation Phase

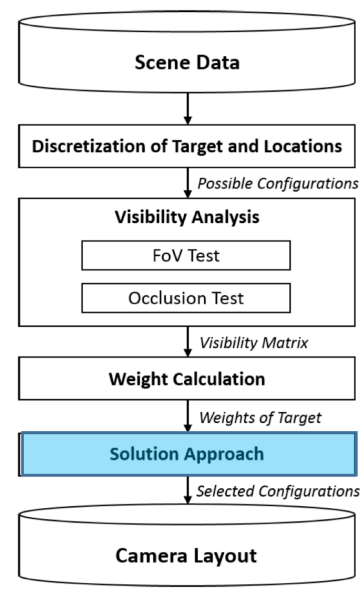
input : C = {set of camera configurations}; O = {set of targets}; $v_{c,o}$ = {visibility matrix}
output : C' = Chosen Camera Configurations
Set $C' = \emptyset$
Set $TC = 0$.
While $(\sum_c cr_c \neq 0$ or $C \neq \emptyset$ or $O \neq \emptyset$ or $TC = 0)$ **do**
  for (camera configuration $c \in \{1, 2, \ldots, C\}$) **do**
    for (target point $o \in O$) **do**
      Compute the relative chance c_o to be covered using (13) $\forall o \in \{1, 2, \ldots, O\}$.
    End for
    Update $cr_c \forall c \in C$ according to (14).
    Select c' with the highest cr_c.
    If $(\sum_c K_c + K_{s'} \geq B)$ **then**
      Set $TC = 1$.
      Exit for
    else
      Set c' in C'.
    End if
    Remove target points covered by c' from O.
    Remove c' from C.
  End for
end while
Return C.

Collaboration-based Local Search Algorithm (COLSA)

1. Adjust the sensing orientations
2. Calculate the weighted coverage rate

Algorithm 2 Local Search Phase

input : C' = Chosen Camera Configurations of Algorithm 1; DX; DY; DZ; DH; DV
output : C'' = Improved Camera Configurations by local search phase
Set $DX, DY, DZ = \{-1, 0, 1\}$.
Set $DH = \{-30, -15, 0, 15, 30\}$.
Set $DV = \{-40, -20, 0, 20, 40\}$.
$C'' \leftarrow C'$.
For (camera configuration $c \in C''$) **do**
  Set $N = \emptyset$
  Initialize c'
  for (each $d_x \in DX$, $d_y \in DY$, $d_z \in DZ$, $d_h \in DH$, and $d_v \in DV$) **do**
    Set $x_{c'}$ to $x_c + d_x$
    Set $y_{c'}$ to $y_c + d_y$
    Set $z_{c'}$ to $z_c + d_z$
    Set ψ_h of c' to $\psi_h + d_h$
    Set ψ_v of c' to $\psi_v + d_v$
    Initialize C_n
    $C_n \leftarrow C'$.
    Change $c \in C_n$ to c'.
    Add C_n to N.
    end for
  end for
  for (camera configuration $C_n \in N$) **do**
    Calculate the weighted coverage rate of C_n using (5)
  end for
  find the best C_{nb} in N.
  if (there is no improvement between C_{nb} and C'') **then**
    exit for
  else
    $C'' \leftarrow C_{nb}$.
  end if
end for
Return C''



Experiment

- Experiment Design

Parameters	Small Size	Large size
Maximum size of 3D space (x_s, y_s, z_s) (meter)	(500, 500, 500)	
Azimuth (ψ_h)	0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°	
Elevation (ψ_v)	30°, 330°, 150°, 210°, 270°	
Average number of camera configurations	42309	73673
Average number of target points	4112	12820
Average total weights	8658	28069
Length of target for each edge (meter)	N(30, 5)	N(50, 10)
Distance between target grid points (Δ_o) (meter)	1	1
Distance between camera grid points (Δ_s) (meter)	4	6
Minimum covered target points	10	20
Average computation time for visibility analysis (minutes)	11.63	26.76

Experiment

- Experiment Result
  - Non-weighted

Budget Limitation (USD)	Algorithms	Small		Large	
		Computation Time (Min)	Coverage Rate (%)	Computation Time (Min)	Coverage Rate (%)
5,000	BPSO	1.72	28.55	14.44	11.22
	BGA	2.71	40.88	22.51	19.59
	Greedy	0.16	48.03	0.7	20.07
	COLSA	0.54	52.75	1.92	20.94
10,000	BPSO	1.9	40.8	16.3	18.21
	BGA	2.72	61.83	23.35	33.02
	Greedy	0.31	71.17	1.54	37.98
	COLSA	1.17	81.24	3.56	41
20,000	BPSO	19.73	60.35	53.51	29.72
	BGA	9.44	79.7	41.47	48.44
	Greedy	0.61	96.3	2.96	62.37
	COLSA	2.1	98.5	5.98	66.65

Experiment

- Experiment Result
  - Weighted

Budget Limitation (USD)	Algorithms	Small		Large	
		Computation Time (Min)	Weighted Coverage Rate (%)	Computation Time (Min)	Weighted Coverage Rate (%)
5,000	BPSO	2.21	25.97	18.05	11.26
	BGA	2.71	41.44	22.48	20.34
	Greedy	0.21	46.1	0.85	19.1
	COLSA	0.68	52.08	2.56	22.24
10,000	BPSO	2.4	38.76	19.15	17
	BGA	2.77	60.43	23.05	33.94
	Greedy	0.4	73.74	1.83	37.67
	COLSA	1.3	80.3	4.62	40.62
20,000	BPSO	19.87	55.81	42.81	27.32
	BGA	9.51	78.3	34.4	49.18
	Greedy	0.79	96.02	3.63	61.92
	COLSA	2.54	98.39	8.35	66.85

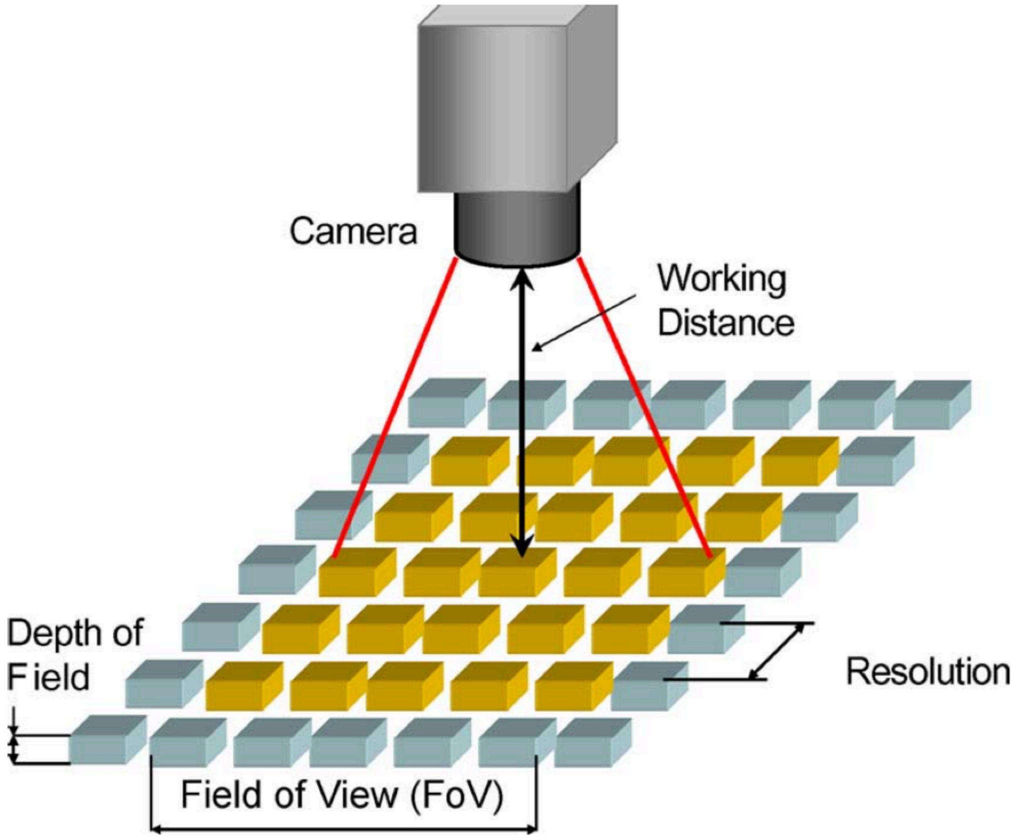
Conclusion

- Addressing of the camera placement problem for maximized weighted coverage with the budget limitation in a 3D environment
- Developing of a new heuristic algorithm
- The second phase of proposed algorithm can be applied extensively for adjustment of angles

Questions?

Literature Review

- Much work relating to camera placement problems for maximization of surveillance target.
- The camera placement problems for maximization of surveillance problem under budge limitations im 3D environment has been far less study.


Camera
Working
Distance
Depth of
Field
Resolution
Field of View (FoV)