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 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 calculated 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:

\[
\overrightarrow{u_{so}} = \overrightarrow{o} - \overrightarrow{s}\\
\psi_h - \frac{\phi_h}{2} \leq \arctan\left(\frac{x_o - x_s}{y_o - y_s}\right) \leq \psi_h + \frac{\phi_h}{2}\\
\psi_v - \frac{\phi_v}{2} \leq \arcsin\left(\frac{z_o - z_s}{\|\overrightarrow{u_{so}}\|}\right) \leq \psi_v + \frac{\phi_v}{2}\\
\|\overrightarrow{u_{so}}\| \leq d
\]

$o$: target point, $s$: camera position, $\psi$: pose
Collaboration-based Local Search Algorithm (COLSA)

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

<table>
<thead>
<tr>
<th>Camera Types</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Angle ($\phi_v$)</td>
<td>51.45</td>
<td>60.95</td>
<td>60.62</td>
</tr>
<tr>
<td>Horizontal Angle ($\phi_h$)</td>
<td>93.91</td>
<td>105.19</td>
<td>104.82</td>
</tr>
<tr>
<td>Working distance with zooming ($d$) (meters)</td>
<td>27.5</td>
<td>15</td>
<td>11.3</td>
</tr>
<tr>
<td>Price (USD)</td>
<td>1085</td>
<td>429</td>
<td>379</td>
</tr>
</tbody>
</table>
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 \((v, o)\)
Collaboration-based Local Search Algorithm (COLSA)

\[ w_o = \begin{cases} 
  3 & \text{if } l < D_1 \\
  2 & \text{if } D_1 \leq l < D_2 \\
  1 & \text{if } D_2 \leq l 
\end{cases} \]

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

- \( R \): 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

\[
\text{maximize } \sum_{o \in O} w_o \cdot y_o / \sum_{o \in O} w_o \\
\text{subject to } \sum_{(s, j_s) \in V_o} c_s \cdot x_{s, j_s} \leq B \\
\sum_{(s, j_s) \in V_o} x_{s, j_s} \geq y_o \\
\sum_{j_s} x_{s, j_s} = 1 \quad \forall s \in S \\
x_{s, j_s} \in \{0, 1\} \quad \forall s \in S \\
y_o \in \{0, 1\} \quad \forall o \in O
\]

<table>
<thead>
<tr>
<th>Indices</th>
<th>$o$</th>
<th>Index of target points, $o \in O$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$j_s$</td>
<td></td>
<td>Index of configurations of camera $s$</td>
</tr>
<tr>
<td>Parameters</td>
<td>$w_o$</td>
<td>Weight of target points</td>
</tr>
<tr>
<td>$c_s$</td>
<td></td>
<td>Cost of cameras</td>
</tr>
<tr>
<td>$B$</td>
<td></td>
<td>Budget Limitation</td>
</tr>
<tr>
<td>Set</td>
<td>$V_o$</td>
<td>Cameras and their configurations that cover target point $o$</td>
</tr>
</tbody>
</table>

| 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

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

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

Algorithm 1 Collaborative Allocation Phase

```plaintext
input : \( C = \{ \text{set of camera configurations}\}; \ O = \{ \text{set of targets}\}; \ v_{c,o} = \{ \text{visibility matrix}\} \\
output : \( C' = \text{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 \\
\hspace{1em} for (\text{camera configuration} \ c \in \{1, 2, \ldots, C\}) \ do \\
\hspace{2em} for (\text{target point} \ o \in O) \ do \\
\hspace{3em} Compute the relative chance \( c_o \) to be covered using (13) \( \forall o \in \{1, 2, \ldots, O\} \).
\hspace{2em} End for \\
\hspace{2em} Update \( cr_c \forall c \in C \) according to (14).
\hspace{1em} Select \( c' \) with the highest \( cr_c \).
\hspace{1em} If (\( \sum_c K_c + K_{s'} \geq B \)) then \\
\hspace{2em} Set \( TC = 1 \).
\hspace{2em} Exit for \\
\hspace{1em} else \\
\hspace{2em} Set \( c' \) in \( C' \).
\hspace{1em} End if \\
\hspace{1em} Remove target points covered by \( c' \) from \( O \).
\hspace{1em} 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**: $C' = \text{Chosen Camera Configurations of Algorithm 1};$  
$DX; DY; DZ; DH; DV$

**output**: $C'' = \text{Improved Camera Configurations by local search phase}$

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 $\psi_h$ of $c'$ to $\psi_h + d_h$
    - Set $\psi_v$ 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

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**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Small Size</th>
<th>Large size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum size of 3D space $(x_s, y_s, z_s)$ (meter)</td>
<td>(500, 500, 500)</td>
<td></td>
</tr>
<tr>
<td>Azimuth $(\psi_h)$</td>
<td>$0^\circ, 45^\circ, 90^\circ, 135^\circ$</td>
<td>$180^\circ, 225^\circ, 270^\circ, 315^\circ$</td>
</tr>
<tr>
<td>Elevation $(\psi_v)$</td>
<td>$30^\circ, 330^\circ, 150^\circ, 210^\circ, 270^\circ$</td>
<td></td>
</tr>
<tr>
<td>Average number of camera configurations</td>
<td>42309</td>
<td>73673</td>
</tr>
<tr>
<td>Average number of target points</td>
<td>4112</td>
<td>12820</td>
</tr>
<tr>
<td>Average total weights</td>
<td>8658</td>
<td>28069</td>
</tr>
<tr>
<td>Length of target for each edge (meter)</td>
<td>N(30, 5)</td>
<td>N(50, 10)</td>
</tr>
<tr>
<td>Distance between target grid points $(\Delta_o)$ (meter)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Distance between camera grid points $(\Delta_s)$ (meter)</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Minimum covered target points</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Average computation time for visibility analysis (minutes)</td>
<td>11.63</td>
<td>26.76</td>
</tr>
</tbody>
</table>
## Experiment

- **Experiment Result**

- **Non-weighted**

<table>
<thead>
<tr>
<th>Budget Limitation (USD)</th>
<th>Algorithms</th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Computation Time (Min)</td>
<td>Coverage Rate (%)</td>
</tr>
<tr>
<td>5,000</td>
<td>BPSO</td>
<td>1.72</td>
<td>28.55</td>
</tr>
<tr>
<td></td>
<td>BGA</td>
<td>2.71</td>
<td>40.88</td>
</tr>
<tr>
<td></td>
<td>Greedy</td>
<td>0.16</td>
<td>48.03</td>
</tr>
<tr>
<td></td>
<td>COLSA</td>
<td>0.54</td>
<td>52.75</td>
</tr>
<tr>
<td>10,000</td>
<td>BPSO</td>
<td>1.9</td>
<td>40.8</td>
</tr>
<tr>
<td></td>
<td>BGA</td>
<td>2.72</td>
<td>61.83</td>
</tr>
<tr>
<td></td>
<td>Greedy</td>
<td>0.31</td>
<td>71.17</td>
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<tr>
<td></td>
<td>COLSA</td>
<td>1.17</td>
<td>81.24</td>
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<tr>
<td>20,000</td>
<td>BPSO</td>
<td>19.73</td>
<td>60.35</td>
</tr>
<tr>
<td></td>
<td>BGA</td>
<td>9.44</td>
<td>79.7</td>
</tr>
<tr>
<td></td>
<td>Greedy</td>
<td>0.61</td>
<td>96.3</td>
</tr>
<tr>
<td></td>
<td>COLSA</td>
<td>2.1</td>
<td>98.5</td>
</tr>
</tbody>
</table>
# Experiment

## Experiment Result

### Weighted

<table>
<thead>
<tr>
<th>Budget Limitation (USD)</th>
<th>Algorithms</th>
<th>Small</th>
<th></th>
<th>Large</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Computation Time (Min)</td>
<td>Weighted Coverage Rate (%)</td>
<td>Computation Time (Min)</td>
<td>Weighted Coverage Rate (%)</td>
</tr>
<tr>
<td>5,000</td>
<td>BPSO</td>
<td>2.21</td>
<td>25.97</td>
<td>18.05</td>
<td>11.26</td>
</tr>
<tr>
<td></td>
<td>BGA</td>
<td>2.71</td>
<td>41.44</td>
<td>22.48</td>
<td>20.34</td>
</tr>
<tr>
<td></td>
<td>Greedy</td>
<td>0.21</td>
<td>46.1</td>
<td>0.85</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td>COLSA</td>
<td>0.68</td>
<td>52.08</td>
<td>2.56</td>
<td>22.24</td>
</tr>
<tr>
<td>10,000</td>
<td>BPSO</td>
<td>2.4</td>
<td>38.76</td>
<td>19.15</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>BGA</td>
<td>2.77</td>
<td>60.43</td>
<td>23.05</td>
<td>33.94</td>
</tr>
<tr>
<td></td>
<td>Greedy</td>
<td>0.4</td>
<td>73.74</td>
<td>1.83</td>
<td>37.67</td>
</tr>
<tr>
<td></td>
<td>COLSA</td>
<td>1.3</td>
<td>80.3</td>
<td>4.62</td>
<td>40.62</td>
</tr>
<tr>
<td>20,000</td>
<td>BPSO</td>
<td>19.87</td>
<td>55.81</td>
<td>42.81</td>
<td>27.32</td>
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<tr>
<td></td>
<td>BGA</td>
<td>9.51</td>
<td>78.3</td>
<td>34.4</td>
<td>49.18</td>
</tr>
<tr>
<td></td>
<td>Greedy</td>
<td>0.79</td>
<td>96.02</td>
<td>3.63</td>
<td>61.92</td>
</tr>
<tr>
<td></td>
<td>COLSA</td>
<td>2.54</td>
<td>98.39</td>
<td>8.35</td>
<td>66.85</td>
</tr>
</tbody>
</table>
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 budget limitations in 3D environment has been far less studied.