Proposed Placement Model for Public CCTV Systems in Student Safety Zones
Considering Surveillance Probability on Pedestrian Streets

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Abstract
This paper proposes a placement model for closed-circuit television (CCTV) cameras to effectively monitor criminal activity on pedestrian streets in student safety zones in South Korea. Although pedestrian streets around schools are potential crime sites, the legal management of and supervisory responsibility for these areas are ill-defined. The increasing demand for public supervision in student safety zones requires the effective control of high-cost CCTV systems. The rational choice perspective and routine activity approach can be used to explain attackers' preferences for criminal activities and the accompanying situational characteristics. Surveillance conditions differ depending on the pedestrian flow and immediate environment. The spatial properties derived from the pedestrian street network affect pedestrian flow. In addition, visibility of the physical environment affects natural surveillance and mechanical surveillance. Quantitative research is presented on the needs for surveillance considering these properties, and a placement model for public CCTV cameras is proposed that uses a genetic algorithm. Following an analysis of surveillance conditions, the model provides information describing the placement and mechanical operation of surveillance cameras. CCTV cameras are routinely installed in student safety zones; the proposed model should contribute to the effective planning and installation of these cameras.

Keywords: CCTV; student safety zone; surveillance; genetic algorithm; environmental design

1. Introduction
Installing CCTV cameras around schools is the main method of mechanical surveillance for crime prevention. Data gathered by the Korean Statistical Information Service in 2010 indicated that 169,570 CCTV cameras were installed in Korea and that the number is growing. Government policies include measures such as increasing the number of CCTVs to counter school violence. While school authorities, including teachers, monitor activity inside schools, the surveillance and regulation of areas around schools have inevitably become the public's responsibility. Having CCTV surveillance around schools is an important means of deterring criminals. According to the Korean Ministry of the Interior (2011), the government will install an additional 14,499 CCTV cameras in student safety zones nationwide by 2015. Most of these cameras have limited surveillance capability because they are concentrated at the front and back gates of 5,855 elementary schools.

The Crime Prevention through Environmental Design (CPTED) approach suggests strategies that include both mechanical and natural surveillance (Crowe, 2000). Mechanical surveillance is needed in areas heavily populated by pedestrians, such as walkways with easy approaches. Crimes can also occur on less-used pedestrian streets with no natural surveillance; in such cases, the fear of crime leads to a demand for mechanical surveillance.

Physical street conditions and the flow of pedestrians must be considered when installing high-cost CCTVs. However, investigating all pedestrian flows at all individual points on the streets surrounding schools at all times of the day is difficult and inefficient. Practical problems can arise after the installation of CCTVs. For example, it is difficult for onsite installers to fully understand the designer's instructions. Even when an approximate installation area is identified, the installer often has to make subjective decisions regarding specific aspects of the surveillance camera's operation. To ensure quality control and the effective use of CCTV cameras, the actual physical environment and pedestrian conditions must be factored into the work order. CCTV cameras are usually installed according to repeated trial-and-error and onsite experience. This approach needs to be reformed to improve efficiency.

This paper presents a placement model for surveillance CCTV cameras, including instructions for
their mechanical operation depending on the appropriate probability of surveillance for each student safety zone. Fig.1. shows the methods of the study: a review of the related research, the proposed public CCTV placement model, and an application of the model.

The related research was reviewed to document the extent of school violence in Korea and investigate the scope of legal responsibility. The criminology research involved considering elements that constitute criminal activity, where such activity occurs, theories that explain these two aspects, and findings on the effectiveness and efficiency of public CCTVs. The findings of other studies were used to prepare the placement model, and a method was developed to quantify the characteristics of an unfavorable street environment. A genetic algorithm was used for optimization of the proposed model for CCTV camera placement. The placement model was applied to the safe zones of elementary schools as a demonstration of the study's findings, and the content and form of the information inputs and outputs were observed.

### Related Research

**Criminal Violations around Schools**
- Surveillance Needs as per Situational Criminology
- Effectiveness and Efficiency of Public CCTVs

**Proposed Public CCTV Placement Model**
- Genetic Algorithm
- Direction of Development
- Spatial Network Analysis
- Implementation of the Model

### Application and Conclusions

Fig.1. Study Procedure

#### 2. Review of Related Research

**2.1 Criminal Violations around Schools**

Violence has been reported around schools for many years (Kim et al., 1997). Eighteen percent of all criminal violations against students occur in such areas: mainly muggings, physical assaults, and sexual violence. The Juvenile White Paper (Moon and Kim, 2007) published by the Korea Government Youth Commission in 2007 reported that physical violence and threats accounted for 21.4% of attacks on youths in 2005 and 20.5% in 2006; muggings accounted for 26.5% in 2005 and 23.3% in 2006. According to a survey of Seoul (Kang et al., 2010), predatory crimes including physical assault, mugging, property damage, larceny, menacing, and sexual assault reached 58.7% of all criminal violations around schools, and physical assaults comprised the highest proportion of crimes around elementary schools. The Ministry of Education reported in 2012 that 12.5% of violence against students occurs when they are walking near schools, vacant lots, empty buildings, and parking lots. Including the other locations, such incidents account for 40.2% of the violence against students. When the proximity to schools is considered, most violence against students occurs around schools.

The level of fear of being victimized varies by region. Wiebe et al. (2013) found that children's and teenagers' fears of crime around schools differed depending on the locational environment. Consequently, differences between local environmental settings should be identified when considering violence around schools.

To examine the scope of legal responsibility with regard to the spatial and temporal aspects of criminal activity, Han and Akiba (2005) compared the judicial precedents of school violence by using cases in Korea and the United States where students were physically injured. Because there is a limit to a school's legal responsibility, foreseeability was identified as a key factor, and the main criterion of their assessment was whether school authorities took proper measures to prevent violence. However, these are vague measures because legal judgments can vary, and the actions needed to prevent school violence are controversial.

Lee (2008) developed CCTV guidelines for child safety zones. He recommended a safe zone with a radius of 300–500 m from the main gate of the child facility. The Ministry of Education (2014) pre-announced legislation for "laws related to student safety and protection." With the increased attention to safety issues, these laws set the safety zone to 200 m from school boundary lines. The Child Welfare Act 2012 of Korea also indicated that mechanical surveillance and recording equipment must be installed at child safety zones, including elementary schools, to prevent crimes such as kidnapping and to record crime situations.

#### 2.2 Surveillance Needs from Situational Criminology

A theoretical exploration of the conditions under which criminal activities occur is needed if CCTV cameras are to be effective at observing potential criminal acts in specific places. This research examines two theoretical perspectives: the routine activity approach and rational choice perspective.

Cohen and Felson (1979) used the concept of direct contact predatory violation and proposed that the probability of a criminal act occurring depends on the factors that constitute the crime and the interactions between those factors. Direct contact predatory violation refers to at least one attacker stealing or damaging at least one other person's property (Clarke and Felson, 1993). Thus, the routine activity approach defines a criminal act as an event that occurs at a point in space and time where there is no guardian to block an attack and a likely offender and suitable target coexist. The routine activity approach posits that school surroundings are areas where possible victims cannot protect themselves from potential attackers. This approach describes the occurrence of criminal events by identifying the factors that facilitate criminal actions and their interactions in space and time. According to the routine activity approach, criminal activities occur when there is an absence of surveillance. For effective surveillance, environmental characteristics must allow...
for surveillance, and someone must be present to implement the surveillance. Thus, surveillance should be strengthened for physical environments with limited visibility and low pedestrian flow.

Becker (1968) used economics to explain the logic behind an attacker's choice of victim and means for the attack. His work led to meaningful research on target selection but has limited practical application owing to the difficulties with quantifying an attacker's various needs and rewards. Clarke and Cornish (1985) accepted and built upon Becker's principal logic to propose the rational choice perspective. They explained a series of criminal decision-making processes depending on the type of criminal act. From the rational choice perspective, an attacker's choice of method for attacking a target depends on the latter's needs, anticipated rewards, and behavioral setting before the crime occurs. If the attacker faces dangers that exceed the needs and anticipated rewards, the attacker's decision will be delayed or suppressed, and the opportunistic elements of the criminal activity in that space and time will be controlled. Even in the same situation, if the criminal's demands and rewards are very high, the likelihood of crime will increase depending on the criminal's inclination or crime type, such as sexual assault, pickpocketing, or kidnapping.

### 2.3 Effectiveness and Efficiency of Public CCTV Surveillance

The use of CCTV is widely known to reduce crime. CCTV is frequently applied as a practical method of crime prevention during construction planning processes. Park et al. (2012) noted that CCTV installation is effective at preventing crime in Korea. They argued that, when installing CCTVs, their number and location must be determined scientifically, and an in-depth analysis of crime patterns must first be conducted. However, such guidelines cannot be implemented in Korea, where public access to criminal records is difficult.

Lim et al. (2013) verified that while the use of CCTV does not significantly reduce serious offenses, it does reduce crimes on public streets. This confirmed Wilson and Sutton's (2003) findings on the crime prevention effects of CCTV. Lim et al. (2013) also found that CCTV's effect on crime prevention depends on the characteristics of the location. Kang et al. (2009) used crime reduction and people's awareness of crime in areas after the placement of CCTV to explain the effects of CCTV installation. They argued that planning for CCTV surveillance has to consider criminals' opportunistic factors. Their research revealed the need for objective CCTV installation plans that incorporate elements of urban architecture.

While research on the effects of CCTV installation has not identified complete solutions, there has been a focus on optimizing the choice of location and number of CCTVs. Rana (2005) used Geographic Information System (GIS) data to improve the location-selection criteria by using a 2D model with equidistant interval divisions. Within the analysis range, the visual openness value at the node was calculated on the flat geometries, and the point with the lower output value was removed. This technique was used to extract the minimum number of points to maximize the openness of visibility.

Additional factors were revealed for optimizing the placement of CCTVs in the study area. First, the physical environments and pedestrian flows that allow for natural surveillance need to be considered. Second, a 3D model should be used rather than a 2D model. The relative locations of the camera and subject being recorded should also be considered. Thus, the camera's mechanical performance and filming operation must be considered. Third, determining the preferred point for the installation of the equipment is important. Lastly, the designer must specify the location for the CCTV and provide the above information to the installer to enable onsite equipment installation as per the placement plan.

Kweon (2014) proposed a model for CCTV installation that maximizes the surveillance area. However, the model does not consider environmental visibility conditions nor the probability of pedestrians, only increasing the surveillance area. This does not improve the existing limits or consider criminals' opportunistic factors as outlined by Kang et al. (2009).

### 2.4 Genetic Algorithm

In the Netherlands, a genetic algorithm was developed (Beasley et al., 1993) to solve the problem of optimization exploration producing approximate results. The genetic algorithm is exploration logic to search for the optimum value by using the concept of natural genetics to allow optimized objects to continue living in the next generation under survival conditions. The selection, crossover, and mutation processes that form the algorithm exploit the population in the preceding generation and calculate the fitness levels. These are then compared and evaluated for repetition in the succeeding generation in order to explore the optimum value.

Jo and Gero (1998) proposed an optimization planning method for a large-scale office layout that uses a genetic algorithm for architectural planning. Their study analyzed and extracted the basic rules required for the design exploration process. Turrin et al. (2011) combined parametric modeling and a genetic algorithm to attempt a performance-based design that incorporates solar transmittance, the structural form, and a cladding system. The above studies focused on optimizing spatial placement and structural planning through a series of analyses under given conditions and arithmetic rules; a method would then be chosen for the optimization.

The model proposed in the present paper explores the optimized placement of CCTV cameras while considering environmental and behavioral conditions. This is the first analysis of the possibility of pedestrians...
using the spatial networks being affected by the physical street environment. These results can then be used to inform the optimized exploration process of a genetic algorithm.

3. Public CCTV Placement Model

3.1 Direction of Development

The proposed installation model for CCTVs on pedestrian streets within student safety zones is as follows. First, given that the pedestrian streets around schools are the main locations for school violence and because the legal responsibility for criminal injustice is unclear, public surveillance activities are required. School safe zones are categorized as areas within a spatial range around schools in which CCTVs are installed. Second, according to the rational choice perspective and routine activity approach, criminals prefer situations where they can satisfy their demands and maximize their rewards. They prefer situations without surveillance. Each individual place on pedestrian streets surrounding schools has a specific possibility of surveillance due to different levels of visual openness and pedestrian flow. Planning for CCTVs requires taking into account the difference in surveillance possibilities according to the visibility conditions and probability of pedestrian traffic. Third, the effective placement and use of high-cost public CCTV systems necessitate the strategic identification of surveillance locations. Because CCTVs will likely be able to provide total surveillance in extensive areas, criminology studies can be used to identify a logical selection process to ensure effective CCTV placement. Fourth, perpetrators consider whether conditions are opportunistic when planning and implementing a crime. Visibility conditions and the probability of pedestrian traffic on the street should therefore be reflected in the CCTV installation plan.

3.2 Spatial Network Analysis

Space syntax theory and visibility graph analysis (Hillier and Hanson, 1984; Turner et al., 2001) have been used to quantitatively investigate the spatial integrity and visual accessibility of urban streets. Links between arranged nodes based on unit spaces or equidistant intervals affected by visual perception can be modeled by using axial maps or visibility graphs as networks. The characteristics of the spatial structures between urban streets have been quantified through these network analyses, although the analyses were initially based on binary links, so all links in the network were quantified homogeneously.

Turner (2001) measured the changes in angles due to links by using the angular distance instead of the binary link for his analysis of the axial map and visibility map and proposed the angular analysis concept. The angular mean depth is calculated by angular analysis of an axial map or visibility graph and explains the flow of pedestrians better than visibility. Desyllas and Duxbury (2001) suggested that visibility (connectivity), which is the most basic measure of a visibility graph, has a higher correlation with pedestrian movement than all other measures based on the axial map.

Table 1. presents the combined examination of space syntax theory and visibility graph analysis. For the analysis of a spatial structure, the visibility graph with its more accurate analysis factors allows for a more accurate spot analysis than the axial map. The angular mean depth obtained from the analysis of direct networks formed with dual visibility lines shows a higher correlation with the pedestrian flow than other measured values based on the binary connectivity from the axial lines and visibility lines. Thus, when the angular mean depth is measured from the visibility graph, the possibility of pedestrian flow can be quantified more accurately.

![Fig.2. Connectivity and Angular Mean Depth](image)

In this study, a visibility graph based on a 3D digital elevation model (DEM) was used. Fig.2. shows the conceptual model. The number of nodes visible from a node $V_o$ is used to calculate the node's connectivity to quantify its visible area determined by the physical conditions. To consider the individual sightline length $|s_i|$ over the visible range $R_o$, the connectivity from the node $V_i$ can be calculated from the equation with $C_n$ normalized between 0 and 1.

To consider the possibility of natural surveillance for CCTV camera placement, the user’s pedestrian possibility was also considered. The angular mean depth was used for this. The spatial placement of the dual visibility lines in Fig.2. is given as an example.
The weighted value used for angular analysis was the angle that forms the dual visibility lines when the visibility line $a$ formed by the movement from $V_x$ to $V_y$ is connected to another visibility line $b$ formed by the movement from $V_1$ to $V_2$. This weighted value is defined as the angular distance in radians. To calculate the angular mean depth $AMD_n$ at each individual node $V_i$, the shortest angular path need to be determined. The shortest angular path is the route with the minimum sum of angular distances among the various routes formed with visibility lines between nodes in the system. The length of the shortest angular path is the sum of the angular distances $s_{ab}$ of this route. One node $V_i$ in the system is connected to many visibility lines and forms a set $D(L)$ of visibility lines. The angular mean depth $AMD_n$ of this node $V_i$ is calculated as the aggregated rate of the shortest angular path lengths $s_{ab}$ within the set of visibility lines over the aggregated angular distance $w_i$ of the dual visibility lines $E(L)$ within the system. This can be expressed by the equation in Fig.2. The angular mean depth calculated to understand the flow of pedestrians is divided into instances with high and low possibilities of pedestrians and is used to calculate the weighted value in the following process. For this process, the results of the angular mean depth $AMD_n$ are normalized to values between 0 and 1.

The weighted average for which the possibility of pedestrian flow is low considers both the angular mean depth $AMD_n$ and connectivity $C_n$. For a point at which the angular mean depth is high, a relatively long shortest path length is required to approach that point and depends on the lower pedestrian possibility (Turner, 2001). Regarding the absence of observers in situations in which crimes can occur, there is a need to reflect on visibility conditions and the possibility of observers passing by which would allow surveillance at these points of the analysis. The weighted value $W_{hc}$ at these points considers both the visibility conditions and the possibility of pedestrians. This is expressed by the formula below. A process, which is explained later, is used to investigate locations where high weight values are assigned; this formula assigns high weighted values in locations with a low possibility of pedestrians.

$$W_{hc} = AMD_n(1 - C_n) \quad (0 < AMD_n < 1) \text{ and } (0 < C_n < 1)$$

Because the points where the angular mean depth is low are correlated with a high possibility of pedestrians, these areas are located in relatively large areas, such as intersections or squares. It is difficult to definitively state that crimes occur because of the absence of surveillance. It is more appropriate to assume that situations are conducive to criminal activities such as sexual assault and pickpocketing. Thus, in these cases, the weighted value $W_{hc}$ only considers the angular mean depth. A high weighted average is assigned to points where there is a high possibility of pedestrians because of the low angular median depth. This is a decision based on the public service objective to install public CCTVs where they can provide benefits to many users. The formula is as follows:

$$W_{hc} = 1 - AMD_n$$

### 3.3 Implementation of the Model

Fig.3. shows the placement model for public CCTVs based on the preceding research, spatial network analysis, and a genetic algorithm. The entire model involves three processes. In the first process, the topography and structure of the area being analyzed are prepared in a DEM by using the GIS data. The obtained data describe the available locations where CCTVs can be installed. Even when a surveillance target on pedestrian streets that are within student safety zones is selected, new equipment with a supporting post needs to be installed. However, the physical formation and structure of the streets around the schools can limit the places available for installation. Existing posts are used in cases where they have already been installed for other purposes. Thus, GIS data on possible placements for CCTV installations are obtained from onsite investigations.

In the second process, the spatial network created with the DEM of the topography and buildings is used to calculate the connectivity and angular mean depth. To optimize the visual openness of a space, the angular mean depth is calculated by measuring the connectivity and expected possibility of pedestrian flow. The visibility value in Turner’s (2001) Depthmap software, or the angular distance of the dual visibility lines, was selected as the weighted value in this study. The network analysis of the dual visibility lines can also be calculated with Hagberg et al.’s (2008) Python/NetworkX. The DEM and results generated above are needed to explore CCTV placements.

In the third process, the information produced in the previous process are input into the Rhino/Grasshopper/Python/Galapagos programming platform, and the ranges of exploration conditions and variables are selected. Depending on the CCTV budget, their number and mechanical operations can be assumed.

To use a genetic algorithm, the weights $W_{hc}$ and $W_{hi}$ discussed earlier are calculated at each step $t$ of the overall process $N$ and evaluated with the genetic algorithm. A series of variables is selected as genes within the stagnant range $R_g$. The gene population includes the camera position, horizontal adjustment $P_h$ of the position, vertical adjustment $P_v$, panning angle $A_p$, tilt angle $A_t$, and focal length $L_f$ of the camera. The objective function $F(t)$ of the genetic algorithm is given as follows:

$$F(t) = \sum_{n} f w_{hc} (P_h, P_v, A_p, A_t, L_f)$$
As shown in Fig. 3., the exploration model was designed to transmit the calculated values of the gene population and the fitness of the variables through the Galapagos engine and implement the genetic algorithm process. Changes in gene populations are connected to the parameter controls of each CCTV camera, and the camera position, surveillance direction, field of view, and nodes under surveillance are then selected. During this process, which precedes the fitness calculation, the CCTV camera placement is reviewed to determine whether interference occurs between the buildings and topography meshes in the CCTV camera sightline between each node within the surveillance area. The weighted value at each node is also recorded. The fitness value is the sum of all of these collected weighted values. This model separates the information into one of two cases—whether the possibility of pedestrians is high or low—and explores the maximum fitness. The arithmetic process that uses the genetic algorithm calculates possible solutions through selection, crossover, and mutation until the maximum fitness satisfies the termination conditions. The calculation is repeated and evaluated until this fitness has not been renewed by other fitness values for the designated generations.

The CCTV placement that is generated when the exit condition is satisfied includes information on the numerical value and graphical output. The numerical value provided by the model includes the coordinates of the installation point, the height of the installation, the planning angle, the tilt angle, the camera’s focal length, its horizontal angle (representing the field of view), and its vertical angle (representing the field of view). By using the graphical information of the observed area, the model presents a frustrum that shows the location of each camera's field of view selected on the DEM.

4. Application

The proposed CCTV camera placement model was applied to the student safety zone of M Elementary School in Daegu City, Korea. The safe zone extends 200 m from the school boundaries and includes the topography, buildings, and pedestrian streets. Before the exploration period, equidistant analysis spots were spaced 2 m apart on the model of the street. Setting a narrower spacing between nodes would excessively increase the calculation load. In this study, a 2 m spacing was used because it allowed a manageable computation process and is an acceptable minimum spacing in surveillance.

<table>
<thead>
<tr>
<th>Determined Constants</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCTVs for Low Pedestrian Flow Area</td>
<td>9</td>
</tr>
<tr>
<td>CCTVs for High Pedestrian Flow Area</td>
<td>11</td>
</tr>
<tr>
<td>Available Installation Spots</td>
<td>96</td>
</tr>
<tr>
<td>CCTV Camera Sensor Size</td>
<td>6 mm</td>
</tr>
<tr>
<td>Pixel Ratio of Sensor (Vertical/Horizontal)</td>
<td>3/4</td>
</tr>
<tr>
<td>Min. Distance of FOV (field-of-view)</td>
<td>0.2 m</td>
</tr>
<tr>
<td>Max. Distance of FOV</td>
<td>40 m</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Variable Ranges</th>
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<tbody>
<tr>
<td>Horizontal Adjustment*</td>
<td>0.3–1.2 m</td>
</tr>
<tr>
<td>Vertical Adjustment*</td>
<td>5–7 m</td>
</tr>
<tr>
<td>Panning Angle***</td>
<td>0°–360°</td>
</tr>
<tr>
<td>Tilt Angle***</td>
<td>0°–90°</td>
</tr>
<tr>
<td>Focal Length</td>
<td>2.8–10.0 mm</td>
</tr>
</tbody>
</table>

* Horizontal adjustment and vertical adjustment distances are measured from the installation points.
** Panning angle is counterclockwise from North.
*** Tilt angle is measured downward from the elevated level after horizontal and vertical adjustments of each camera.

The weighted values of these nodes were calculated and used for the application. The determined conditions and variable ranges given in Fig. 3. were selected, as presented in Table 2. While the number of CCTVs installed is affected by the budget, in this study, nine CCTVs were planned for installation if the number of pedestrians was low and eleven CCTVs if this number was high. Based on the onsite investigation, information for 96 possible installation points were
Table 3. CCTV Camera Surveillance Field of View and Placement

<table>
<thead>
<tr>
<th>Group</th>
<th>Fitness Transition</th>
<th>Visualized CCTV Camera Placement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on Low Pedestrian Probability</td>
<td>Initiation</td>
<td>Termination</td>
</tr>
<tr>
<td>Focus on High Pedestrian Probability</td>
<td>Initiation</td>
<td>Termination</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Camera ID</th>
<th>Hor. Adjmt. (m)</th>
<th>Ver. Adjmt. (m)</th>
<th>Tilt Angle (°)</th>
<th>Panning Angle (°)</th>
<th>Focal Length (mm)</th>
<th>Hor. FOV (°)</th>
<th>Ver. FOV (°)</th>
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<tbody>
<tr>
<td>L0</td>
<td>0.3</td>
<td>5.3</td>
<td>49</td>
<td>100</td>
<td>2.8</td>
<td>59.7</td>
<td>52.1</td>
</tr>
<tr>
<td>L1</td>
<td>0.5</td>
<td>5.5</td>
<td>51</td>
<td>216</td>
<td>3.1</td>
<td>57.2</td>
<td>49.3</td>
</tr>
<tr>
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<td>0.5</td>
<td>5.6</td>
<td>55</td>
<td>242</td>
<td>2.8</td>
<td>59.7</td>
<td>52.1</td>
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<tr>
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<td>0.3</td>
<td>5.3</td>
<td>56</td>
<td>213</td>
<td>3.1</td>
<td>57.1</td>
<td>49.1</td>
</tr>
<tr>
<td>L4</td>
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<td>5.4</td>
<td>53</td>
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</tr>
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<td>L5</td>
<td>0.4</td>
<td>6.0</td>
<td>60</td>
<td>185</td>
<td>3.3</td>
<td>55.6</td>
<td>47.6</td>
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<td>41.4</td>
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<td>52</td>
<td>182</td>
<td>2.8</td>
<td>59.7</td>
<td>52.1</td>
</tr>
<tr>
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<td>6.0</td>
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<td>155</td>
<td>2.8</td>
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</tr>
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<td>5.1</td>
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<td>2</td>
<td>2.8</td>
<td>59.7</td>
<td>52.1</td>
</tr>
<tr>
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<td>5.7</td>
<td>61</td>
<td>323</td>
<td>2.8</td>
<td>59.7</td>
<td>52.1</td>
</tr>
<tr>
<td>H2</td>
<td>0.5</td>
<td>5.3</td>
<td>60</td>
<td>186</td>
<td>3.2</td>
<td>56.6</td>
<td>48.7</td>
</tr>
<tr>
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<td>5.4</td>
<td>47</td>
<td>167</td>
<td>2.8</td>
<td>59.7</td>
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<tr>
<td>H4</td>
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<td>194</td>
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<td>H7</td>
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<tr>
<td>H9</td>
<td>0.5</td>
<td>5.3</td>
<td>49</td>
<td>186</td>
<td>2.8</td>
<td>59.7</td>
<td>52.1</td>
</tr>
<tr>
<td>H10</td>
<td>0.3</td>
<td>6.3</td>
<td>55</td>
<td>41</td>
<td>3.4</td>
<td>54.5</td>
<td>46.4</td>
</tr>
</tbody>
</table>

* Each yellow-colored frustum represents the CCTV camera's FOV (field-of-view). Each red-colored zone indicates the area under surveillance.

entered. Information on the sensor size, pixel ratio of the sensor, and field of view related to the mechanical operations of the CCTV was entered.

To select the variable range, detailed location controls, surveillance directions, and focal length related to the camera installation were entered. The information was collected during the exploration process depending on the budget, onsite conditions, and equipment.

The model was applied as indicated in Table 3. The exploration process underwent 13,904 generations in areas with the possibility of low pedestrian flow and 22,251 generations in areas with the possibility of high pedestrian flow. Table 3 summarizes the fitness transitions. The visualized CCTV camera placement (Table 3.) represents the camera's field of view and observed nodes on the DEM. These installation locations for the camera and surveillance points can be provided by using numerical information. The proposed model provides instructions for the CCTV camera installer regarding the camera's location as horizontal and vertical adjustments. The model also produces the camera's direction information as the tilt angle, panning angle, focal length, and field-of-view.

The CCTV camera placement shown in Table 3. indicates that six out of nine CCTVs were concentrated in those areas on dead-end streets where there is a low possibility of pedestrian flow. Two cameras (L7 and L8) were placed at points overseeing dead-end streets. This supports the need for strengthening surveillance in areas with a low number of pedestrians, thus supporting surveillance where natural surveillance is difficult. The location of camera L6 showed the limitations of the scope of analysis on the weighted value. When the boundary of the area of analysis was approached, the calculated weighted average indicated that this area included dead-end streets, even though the streets were not actually dead ends. These problems will be corrected when the spatial scope of analysis is expanded. In the areas with a high possibility of pedestrians, cameras were mainly placed at intersections. The surveillance of many people is possible here because of the high pedestrian flow.

If a motivated criminal joins the pedestrian group, the CCTV will monitor the potential victims and the attacker trying to select a victim. In two surveillance cases, CCTV cameras L7 and H9 were placed in the same location but with different mechanical operations. This means that in both cases, surveillance was required but the directions of the surveillance differed.

5. Conclusion

A CCTV placement model is proposed that optimizes the effectiveness of positioning such cameras to record crimes by considering the opportunistic characteristics of increased criminal activity on pedestrian streets near schools. The growing number of installations indicates the need for the effective and efficient installation of CCTVs.

When considering the crime prevention and surveillance functions of CCTVs, the rationale used to select a victim and carry out a crime according to the rational choice perspective and routine activity approach can also be applied to CPTED implementation. It is difficult for CCTVs to be used for surveillance in all public spaces, and these installations should therefore be performed selectively by considering the visible condition of the built...
environment and possibility of passing pedestrians. This research used regional differences in relation to the opportunistic characteristics of crimes in order to develop an optimized model for CCTV camera placement. The proposed model provides the optimal quantitative data for camera placement, directions, and surveillance areas and their graphical geometries on a 3D map of the student safety zone.

The exploration model for CCTV placement estimates the fitness values of the points observed with the DEM, spatial network analysis, and camera and uses a genetic algorithm to formulate the exploration process. This study was focused on the fact that visibility conditions differ according to the regional location and that the pedestrian flow varies according to the street layout. These differences were quantified by using a weighted value calculated from the connectivity and angular mean depth. The exploration process was carried out to consider the possibility of pedestrians. In this process, the use of the genetic algorithm involves repetitive manual work and offsets the inefficiency of high-cost optimization work. The model produced quantitative results and was able to generate detailed information on the proposed placement and operation of CCTV cameras.

The proposed CCTV camera placement model should facilitate effective installation plans for CCTVs. To enable the installer to optimize CCTV installation, detailed work orders describing the locations and mechanical operation of the CCTVs must be provided onsite. The model’s capacity to apply the series of processes repeatedly is a result of this research.

The analysis of the weighted values showed an edge effect due to the limits of spatial scope and needs to be improved through research to determine how to control the scope of the spatial structure. In addition, the proposed model does not target CCTV placement in exceptional settings such as excessively segregated school safety zones with inordinately low pedestrian density, which are not common in Korea. This research used simplified variables related to crimes for spatial analysis followed by an optimization process of CCTV surveillance camera placement. A complete solution cannot be immediately achieved that considers all aspects of environmental criminology. Further research is required to expand understanding and capabilities with regard to crime prevention through environmental design.

References


