Multi-Objective Optimization of CCTV Placement: A Case Study at Bukidnon State University

Manuel Chad G. Agurob[1*], Noel Lacpao[2] and Ulysses P. Daug[1]
[1]College of Technologies
[2]College of Arts and Sciences
Bukidnon State University
Malaybalay City, Bukidnon 8700 Philippines
[*]*manuel_chad@buksu.edu.ph*

Date received: August 10, 2024
Revision accepted: December 9, 2024

Abstract

Optimizing closed-circuit television (CCTV) camera placement in open-field environments is essential to enhance surveillance coverage while minimizing costs. This study addressed this challenge using a multi-objective optimization approach, employing the Non-dominated Sorting Genetic Algorithm II (NSGA-II) to balance coverage efficiency and cost-effectiveness. The method integrated grid-based layouts with varying densities and allowable camera orientations to identify optimal camera configurations. Bullet and omnidirectional cameras, characterized by differing angles of view (AOV) and depth of field (DOF), were strategically deployed to achieve comprehensive surveillance coverage. To validate this approach, the study focused on Bukidnon State University (BukSU), where wide-open campus areas presented unique monitoring challenges. Using Google Satellite imagery, optimal camera placements were determined, and the impact of grid density and camera orientation flexibility on cost and coverage was evaluated. Results showed that dense grid patterns with finer camera orientations (e.g., 45° intervals) maintained stable costs while improving positioning flexibility and reducing the need for additional cameras. In contrast, less dense grids with limited camera orientations (e.g., 90° intervals) increased costs due to the higher number of cameras required to achieve adequate coverage. Based on simulations, this study provided valuable insights for institutions aiming to enhance security in large, open spaces. By emphasizing the importance of grid density and flexible camera orientations, it contributed to the broader field of cost-efficient, large-scale surveillance optimization and offers a practical framework for addressing similar challenges in other settings.

Keywords*:* CCTV camera placement, cost-effective surveillance, grid density, multi-objective optimization, surveillance coverage efficiency

1. Introduction

In recent years, optimizing camera coverage for surveillance in open fields, such as school campuses, has become increasingly important to enhance security while addressing the unique challenges posed by large-scale environments. Despite various proposed solutions, balancing coverage, cost, and efficiency remains a persistent challenge, particularly for environments with budget constraints.

Several studies have introduced methods to maximize camera coverage while controlling costs and resource use. Introduced by Altahir *et al.* (2017), a dynamic programming approach to increase total coverage by reducing overlap, while Suresh *et al.* (2020) focused on optimizing multi-camera configurations to cover large, open areas with minimal redundancy, a key concern for campuses. Similarly, Han *et al.* (2019) emphasized the use of location-based data to improve camera placement, which is particularly relevant for complex environments like universities, where security needs vary across different zones. These approaches not only enhance coverage but also address budget limitations, which are common in educational settings.

In dynamic environments such as university campuses, balancing coverage and cost constraints is essential for efficient surveillance. Yang *et al.* (2018) underscored the importance of multi-objective optimization to manage coverage, physical obstructions, and financial limitations – all of which are crucial for achieving effective surveillance. Walton *et al.* (2012) further highlighted the role of public perception, noting that while some students appreciate the increased sense of safety from closed-circuit television (CCTV) systems, others express privacy concerns. These findings emphasize the importance of strategic placement that considers both security needs and public acceptance. Also, determining the exact position and orientation of cameras in large, open areas presents additional challenges (Golparvar-Fard *et al.*, 2013). Optimally placing cameras requires consideration of several factors, including the varying types of cameras and their coverage, the resolution requirements for specific tasks, the presence of environmental obstructions, and the limited budgets often available for large-scale surveillance systems (Hamledari *et al.*, 2017; Li *et al.*, 2017). Consequently, the placement of cameras represents a constraint-based optimization problem (Contreras *et al.*, 2017) where multiple objectives must be balanced to achieve efficient surveillance coverage. Thus, the placement of cameras demands a constraint-based optimization approach, where the careful balancing of multiple objectives – such as maximizing coverage, addressing environmental obstructions, meeting resolution requirements, and adhering to financial constraints – is essential to achieving both efficient and effective surveillance coverage. However, while these strategies are critical, existing models have struggled to simultaneously address these complex factors, particularly in large-scale environments like university campuses. This limitation creates a gap in the literature that this study aimed to fill, by developing a more comprehensive approach to optimizing CCTV placement in open fields under varied security needs and budget constraints.

This study aimed to address the challenges of optimizing CCTV placement in open-field environments by adapting the multi-objective optimization techniques introduced by Yang *et al.* (2018). Specifically, this research applied these techniques to the unique context of university campuses, where challenges such as large open spaces, varying activity levels, and diverse security needed complicate surveillance strategies. The goal was to ensure that a minimal number of cameras can be used to effectively cover key areas, maximizing efficiency while adhering to budget constraints. The study integrated Google Satellite imagery to visually present and support optimal camera placements at Bukidnon State University (BukSU). It examines two types of surveillance cameras employed to optimize coverage and cost efficiency.

The bullet camera (DS-2CD1023G0E-I [2022], Hikvision, China) is a cylindrical camera designed for focused, long-range monitoring of specific areas and is commonly utilized in outdoor security systems. The bullet camera, for instance, features a 2.8 mm lens with an 81.2° angle of view, rendering it ideal for targeted surveillance applications. In contrast, the omnidirectional camera (DS-2CD63C5G1-IVS [2023], Hikvision, China) captures a 360° panoramic view, thereby ensuring broad coverage without the necessity for repositioning. For example, the omnidirectional camera is equipped with a 12 MP fisheye lens, facilitating comprehensive monitoring in expansive environments. The names of these cameras are used generically throughout the study to delineate functional categories, irrespective of specific make or model. This approach streamlines the discussion while preserving clarity regarding the roles and capabilities of each camera type in achieving efficient surveillance configurations.

2. Methodology

This research began with a comprehensive evaluation of the existing CCTV infrastructure at BukSU, Malaybalay City, Bukidnon, focusing on identifying both surveillance gaps and areas for optimization. The problem was framed as a coverage problem, where the objective was to monitor the largest possible area while adhering to budgetary constraints. Two types of cameras were incorporated into the analysis: bullet cameras, known for their fixed positions and varying focal lengths, and omnidirectional cameras, which offer 360° coverage. These camera types were selected for their ability to address different surveillance needs across the campus. Key parameters such as AOV, which defines the angular range a camera can capture, and DOF, the distance range where objects remain in focus, are essential in determining the optimal placement of cameras. These technical characteristics directly influence the cameras' effectiveness in covering identified surveillance zones.

To achieve the dual goals of maximizing coverage and minimizing costs, multi-objective optimization techniques were employed. Validation of this approach was conducted in selected open areas of the campus that currently lack CCTV systems, representing potential security vulnerabilities. These areas provided an ideal setting for testing and validating the optimized surveillance configurations. The overall aim was to develop a cost-effective and scalable surveillance solution that enhances BukSU's security infrastructure while balancing coverage and budget efficiency.

2.1 Maximum-coverage Problem

The goal was to determine the optimal positions for cameras in a way that all critical areas were monitored at the lowest possible cost. This involved strategically selecting and positioning cameras to cover as much area as needed but within a limited budget. The approach ensured that the surveillance system is economically feasible, which is crucial for large-scale projects with budget constraints.

The maximum-coverage problem in surveillance systems focuses on maximizing the visual coverage of a given area while working within the constraints of a limited budget, C_o. The objective layout, V_o, consisted of connected regions that may have nonconvex shapes or internal obstructions, requiring strategic camera placement. Candidate cameras, Φ, defined by their location, L, orientation A, and camera attributes like AOV and DOF, were optimized to cover as much of the target area as possible.

Objective $\max_{\emptyset_i \in \Phi} \cup V(\emptyset_i) \cap V_o$ (1)

Subject to
$$\sum_{\emptyset_i} C(\emptyset_i) \leq C_o$$
$$\emptyset_i \left(x_i, y_i, \alpha_i, \theta_i, \rho_i\right) \in \Phi$$
$$(x_i, y_i) \in L,\ \alpha_i \in A, \theta_i \in \Theta, \rho_i \in \rho \quad (2)$$

The objective function shown in Equation 1 was to maximize the union of visible regions, $V(\emptyset_i)$, that were covered by the cameras, $\emptyset_i$. This ensured that the total surveillance coverage was as extensive as possible, particularly for areas defined by the V_o. The function captured how much of the target was effectively monitored by the camera configuration. The intention was to maximize the union of the visible regions covered by the cameras while ensuring the total cost remained within the budget as indicated in Equation 2. The optimization is subject to a total cost constraint $\sum_{\emptyset_i} C(\emptyset_i) \leq C_o$, where $C(\emptyset_i)$ represents the cost of deploying a specific camera configuration $\emptyset_i$, and C_o is the maximum allowable budget. This ensured that the optimization process adhered to financial limitations. Each camera was characterized by its location (x_i, y_i), orientation α_i, angle of view, θ_i, and depth of field, ρ_i. These variables were optimized to ensure that the cameras were positioned and oriented to maximize their coverage area while meeting cost constraints. This required a careful balance between camera characteristics, positioning, and budget constraints to achieve efficient and comprehensive coverage, particularly in complex areas with irregular geometry. This model provided a systematic framework for optimizing surveillance in large, open environments.

The optimization process evaluated various configurations of camera placements to find the one that provides the necessary surveillance coverage at the lowest expense. This involved considering different types of cameras, each with its specific cost and coverage capabilities, and determining the best combination to meet the surveillance needs.

Figure 1 illustrates two types of camera models: a bullet camera and an omnidirectional camera. In Figure 1a, the bullet camera is depicted with a fixed AOV and DOF. The orientation of the bullet camera refers to the fixed direction it faces, limiting its coverage to a narrower, fan-shaped area. This made bullet cameras ideal for focused surveillance, where detailed monitoring of specific zones was required, but their field of view and orientation were constrained to a particular direction.

The omnidirectional camera (Figure 1b) is shown with a 360° AOV, providing a full, circular field of view. This type of camera does not rely on a specific orientation, as it can capture all directions simultaneously. The DOF in the omnidirectional model still plays a role in determining the clarity of images over varying distances. The circular coverage pattern is well-suited for open areas or spaces where broader, all-around monitoring is needed.

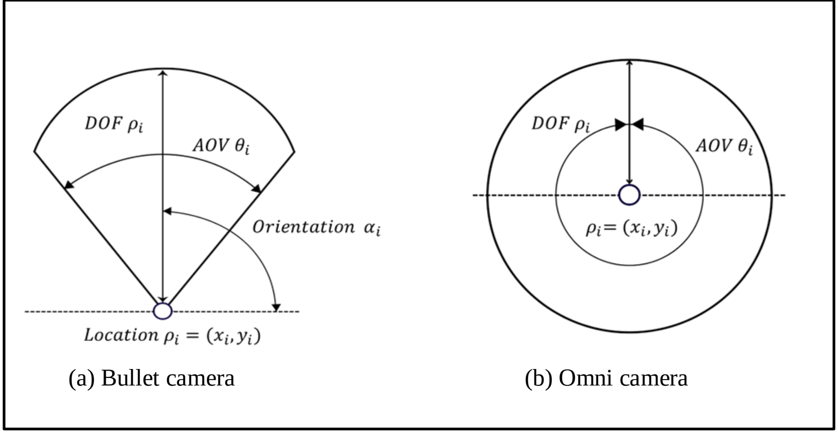
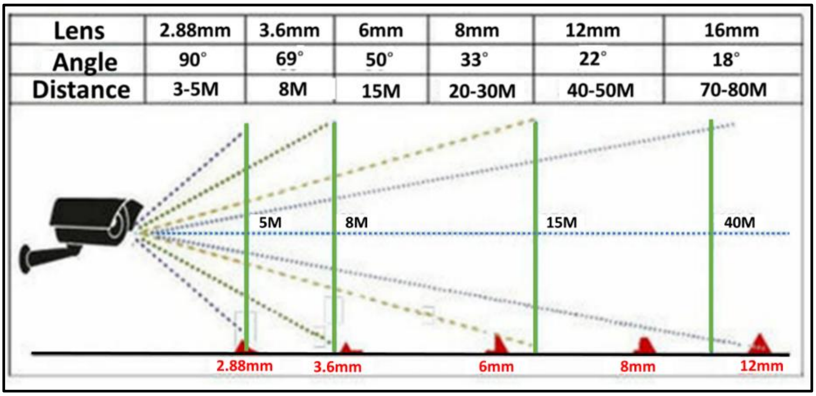


Figure 1. Coverage models for bullet cameras with fixed AOV and DOF (a); and omnidirectional cameras with 360° AOV and variable DOF (b)

2.2 Types of CCTV Cameras and Parameters

Figure 2 illustrates the relationship between lens focal length, AOV, and effective monitoring distance for different types of surveillance cameras, which is crucial for understanding how various camera specifications impact their surveillance capabilities. The figure lists various focal lengths, such as 2.8, 3.6, 6, 8, 12, and 16mm, each corresponding to different camera models. For each focal length, the corresponding angle of view is provided, showing a decrease in the angle as the focal length increases. Additionally, the effective monitoring distance for each focal length is indicated, demonstrating that cameras with shorter focal lengths have wider fields of view but shorter monitoring distances, whereas those with longer focal lengths have narrower fields of view but can monitor objects from farther away. Understanding the interplay between focal length, angle of view, and monitoring distance is essential for the optimal placement of surveillance cameras. In the context of research on optimizing camera placement, these parameters significantly influence decisions on positioning cameras to maximize coverage while adhering to budget constraints. Cameras with shorter focal lengths, such as 2.8 and 3.6 mm, are suitable for monitoring broad areas at close distances, making them ideal for locations where wide coverage is more critical than distance, such as building entrances or small courtyards. In contrast, cameras with longer focal lengths, such as 8, 12, and 16 mm, are better suited for focused monitoring over long distances, useful for corridors, perimeter monitoring, or any area requiring detailed observation from a distance.



Lens	2.88mm	3.6mm	6mm	8mm	12mm	16mm
Angle	90°	69°	50°	33°	22°	18°
Distance	3-5M	8M	15M	20-30M	40-50M	70-80M

Figure 2. Camera visibility over distance (Chiu, 2016); camera visibility declines over distance regardless of camera mobility

Omni-directional CCTV cameras provide a distinct advantage in surveillance due to their 360° field of view. Unlike bullet or dome cameras, which have a limited angle of view and require precise orientation to cover specific areas, omni-directional cameras can monitor an entire surrounding area from a single point. This characteristic makes them particularly suitable for open spaces where comprehensive coverage is essential without the need for multiple cameras or frequent adjustments. The provided figure includes the specifications for omni-directional cameras, highlighting their ability to cover a full circle around their location. The angle of view for these cameras is a complete 360 degrees, meaning they capture all directions simultaneously. The DOF determines the effective range within which the camera can monitor activities. For instance, omnidirectional cameras with a focal length of 1.05 mm have a DOF that typically covers a distance of around 8 m, while those with a focal length of 1.1 mm can cover up to 10 m.

Camera specifications are critical in the context of optimizing surveillance systems, as omnidirectional cameras are ideal for monitoring large, open areas such as plazas, parking lots, and open fields. Their ability to provide uninterrupted coverage around their installation point simplifies the placement process and reduces the need for multiple cameras, thus lowering overall costs and simplifying maintenance. The intrinsic advantage of omnidirectional cameras lies in their comprehensive coverage without the necessity for specific orientation adjustments. This feature makes them highly efficient for surveillance purposes, ensuring that no blind spots are left in the monitored area. The provided figure visually represents how these cameras' specifications impact their coverage capabilities, emphasizing their suitability for scenarios requiring full circular monitoring.

By optimizing the placement of cameras, the study helped administrators deploy an efficient surveillance system that maximizes security and monitoring effectiveness while adhering to budget limitations. The practical outcome was a surveillance setup that ensures all critical areas were observed, enhancing site safety and operational oversight without incurring unnecessary costs.

2.3 Optimization Techniques

In a multi-objective optimization model, the unique capabilities of omnidirectional cameras are leveraged to achieve maximum coverage with minimal resources. By incorporating their 360° AOV and defined DOF into the optimization algorithm, these cameras can be strategically placed to cover extensive areas effectively. The algorithm evaluates potential positions and selects optimal placements to balance the need for wide coverage and cost constraints. This study employed the Non-dominated Sorting Genetic Algorithm II (NSGA-II) to optimize surveillance camera placement, building on a methodology originally designed for dynamic environments such as construction sites with continuously changing layouts and obstructions (Yang *et al.*, 2018). These environments required frequent adjustments to camera configurations, with the approach balancing the dual objectives of maximizing coverage and minimizing costs to effectively manage dynamic and unpredictable conditions.

In contrast, this research adapted the framework to a static environment, specifically the open-field layout of BukSU. Static environments pose distinct challenges, including limited placement flexibility and the absence of dynamic obstructions. To address these challenges, the study introduced refinements to the original methodology, emphasizing grid-based camera placement and orientation strategies. A key adaptation involved exploring varying grid densities and camera orientation intervals (e.g., 45° and 90°), enabling more precise placement and coverage optimization in fixed layouts. These refinements were essential for maximizing surveillance efficiency without requiring additional cameras – a critical consideration for cost-sensitive environments like university campuses.

To enhance the practical applicability of the optimized placements, the study incorporated Google Satellite imagery, bridging the gap between theoretical models and real-world implementation. Satellite imagery provided a detailed map of the campus layout, highlighting high-priority surveillance zones and potential obstacles. This enabled the algorithm to generate camera placement solutions that were both effective and feasible within the campus's physical constraints. The research further tailored its camera deployment strategies by integrating both bullet and omnidirectional cameras. Bullet cameras were deployed for focused monitoring of high-priority areas, such as entrances and high-traffic zones, while omnidirectional cameras were utilized for broad coverage of open spaces. This strategic integration leveraged the unique strengths of each camera type to ensure comprehensive surveillance while minimizing costs. By adapting the NSGA-II framework to the specific challenges of static environments and incorporating additional elements, the study demonstrated the versatility of the approach and provides valuable insights for optimizing surveillance systems in fixed, open-field settings.

The NSGA-II is an evolutionary algorithm for solving multi-objective optimization problems. It initializes a population of solutions, evaluates their performance across multiple objectives, and ranks them using non-dominated sorting. To maintain diversity, a crowding distance metric prioritizes well-distributed solutions. Genetic operations like crossover and mutation introduce variability, while selection retains the best solutions based on rank and diversity. The process repeats over generations until a termination criterion is met, producing a set of Pareto-optimal solutions. NSGA-II was effective for balancing trade-offs, as demonstrated in this study's optimization of CCTV camera placement.

The primary objective was to maximize coverage while minimizing costs, a crucial concern for large areas on the BukSU campus, where CCTV systems have yet to be installed. By employing the NSGA-II algorithm, a fast and elitist multi-objective genetic algorithm, this study sought to balance the need for comprehensive surveillance with the financial constraints typical of university budgets. The algorithm allowed for the identification of optimal camera configurations, ensuring that the selected placements provide the broadest coverage while remaining cost-efficient. The adaptation proved particularly effective in addressing the specific security requirements of open, uncovered university environments, offering a scalable solution that can be replicated in similar settings. This study, therefore, contributed to the broader understanding of CCTV optimization in educational institutions, bridging the gap between theoretical models and practical applications while maintaining budgetary feasibility.

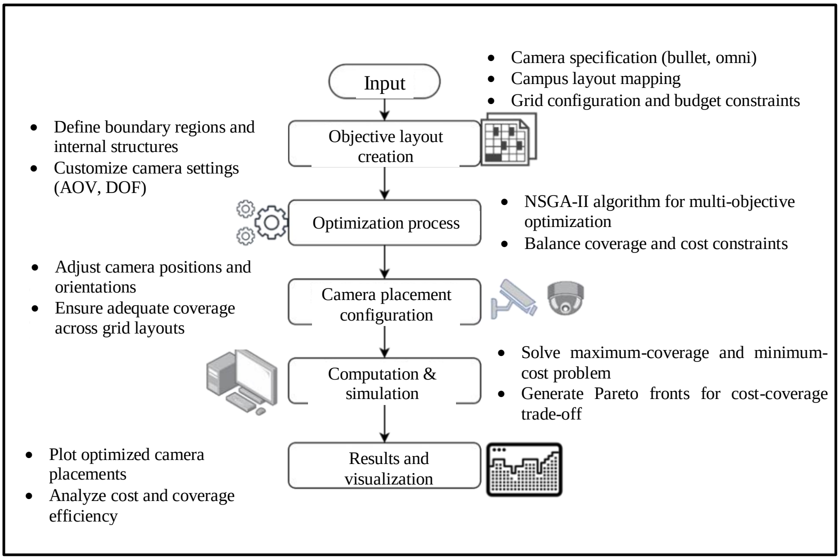


Figure 3. Block diagram illustrating the key steps of the CCTV optimization process

The block diagram in Figure 3 outlines the step-by-step methodology for optimizing CCTV camera placement at BukSU. It began with essential data such as camera specifications such as bullet and omnidirectional cameras, and the mapped layout of the campus was collected. This foundational data, including grid configurations and budget constraints, was critical for informing the subsequent optimization steps. Then the campus's physical features, including external boundaries and internal structures, were defined. High-activity area and vulnerable areas were prioritized, with camera parameters like AOV and DOF being factored in to maximize coverage. Following this was the optimization process, which used the NSGA-II algorithm – a multi-objective optimization technique. This algorithm balanced two key factors: maximizing surveillance coverage and minimizing installation costs. It processed the input data and objective layout to determine the most effective camera configurations. The camera configured the placement and orientation of the cameras. This fine-tuning ensured that blind spots were avoided, and all critical areas were efficiently covered, with both bullet and omnidirectional cameras positioned according to the optimized layout. Simulations were run to test the effectiveness of the proposed layout. This phase solved maximum-coverage and minimum-cost problems, producing Pareto fronts that illustrated the trade-offs between cost and coverage. Finally, the results and visualization stage displayed the optimized camera placements, emphasizing areas with enhanced surveillance coverage and cost efficiency. This helped university administrators make well-informed decisions about upgrading their security systems.

3. Results and Discussion

In the analysis of the BukSU grounds, Google Satellite imagery was utilized to map the external boundaries and internal structures, providing a detailed and comprehensive view of the campus layout. As shown in Figure 4, the satellite image clearly outlined the external boundary, marked by yellow lines, encompassing an area of 2,508 m^2 (43 x 57m). This visual representation was integral to the strategic planning of CCTV placement, ensuring that potential camera locations could be identified with precision. The areas selected for camera installation focused on key internal structures and boundary lines, optimizing coverage in the most critical and high-traffic zones.

This integration of satellite data proved essential in maximizing surveillance coverage while addressing the unique spatial challenges presented by open campus areas. The mapping process allowed for the identification of areas that were particularly vulnerable due to the absence of existing CCTV infrastructure. These selected open grounds provided a scalable and cost-effective solution, enhancing security, and safeguarding the wellbeing of students, faculty, and staff. This approach ensured a robust surveillance framework that aligns with the university's security objectives, particularly in large, uncovered spaces that required comprehensive monitoring.

A detailed comparison of various CCTV camera models, including both bullet and omnidirectional types, based on their specifications such as focal length, AOV, DOF, and price is presented in Table 1. The bullet cameras (B1-B6) varied in focal length, ranging from 2.8 to 16 mm, offering different angles of view and depth of field. As the focal length increases, the angle of view became narrower, while the depth of field extends, enabling a clearer focus on more distant areas. The bullet cameras were priced between Php 2,990 and 4,500, with higher prices corresponding to greater focal lengths and deeper fields of view.

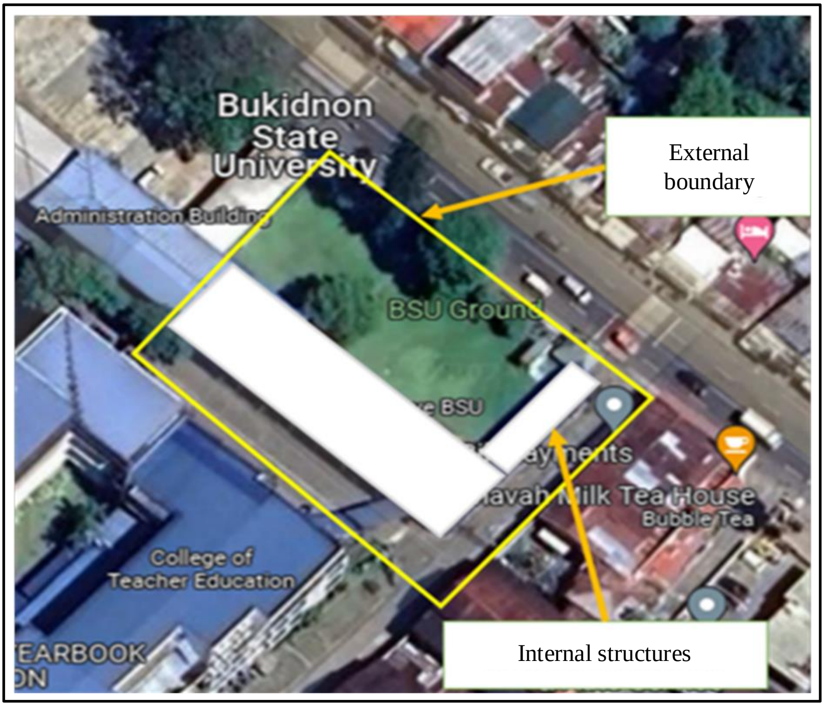


Figure 4. Google Satellite image of BukSU, highlighting the external boundary and internal structures for optimal CCTV placement

On the other hand, the omnidirectional cameras (O1, O2) offered 360° coverage, making them ideal for broad surveillance in open areas. Their depth of field was relatively shallow, ranging from 8 to 10 m, but they provided full panoramic monitoring. These cameras are more cost-effective, with prices ranging from Php 2,880 to 3,120. This requirement could be modeled as a maximum-coverage problem, demonstrating how to place various cameras to monitor as many areas as possible within a limited budget. Conversely, if a certain proportion of areas must be visible at all times, the problem could transform into a minimum-cost problem, showing how to economically cover all key positions. By selecting the right combination of these cameras, it is possible to achieve optimal surveillance coverage that balances extensive monitoring with cost efficiency, ensuring effective and secure surveillance for environments like the selected grounds.

Table 1. Specifications parameters for optimal placement of surveillance cameras (bullet and omni models) with prices in Php

Camera type	Model	Focal length (mm)	AOV (°)	DOF (m)	Price (Php)
Bullet	B1	2.8	81.2	11.7	2,990
Bullet	B2	3.6	67.4	15	3,180
Bullet	B3	6	43.6	25	3,540
Bullet	B4	8	33.4	33.3	3,840
Bullet	B5	12	22.6	50	4,200
Bullet	B6	16	17.1	66.7	4,500
Omni-directional	O1	1.05	360	8	2,880
Omni-directional	O2	1.1	360	10	3,120

The selection of camera type and model depend on the specific surveillance requirements of different areas within the campus. Bullet cameras, with their varied focal lengths, are better suited for focused surveillance in specific, targeted areas, especially where longer distances need to be monitored. In contrast, omnidirectional cameras are more appropriate for broader coverage, such as monitoring open fields or large common areas where 360° visibility is needed.

In terms of cost, omnidirectional cameras are more affordable than higher-end bullet cameras, making them a cost-effective choice for general surveillance. However, to ensure comprehensive coverage in areas that require more detailed monitoring at greater distances, bullet cameras with longer focal lengths, like models B5 and B6, would be more suitable despite their higher cost.

3.1 Grid-Based Discretization of Layout and Candidate Cameras

Figure 5 displays four different surveillance camera coverage layouts at BukSU, captured via Google Satellite, illustrating various configurations of camera placements and their strategic implications for optimizing coverage. The first layout shows a dense grid pattern with a high number of cameras, emphasizing comprehensive coverage to ensure no part of the grounds is left unmonitored. This configuration aimed to maximize coverage but may involve higher costs due to the increased number of cameras. The second layout, with a slightly less dense grid, strategically places cameras to cover key areas while reducing redundancy, balancing extensive coverage and cost-efficiency by focusing on critical zones. The third layout features fewer cameras, each with a wide field of view, optimizing placement to monitor larger sections of the grounds with fewer devices.

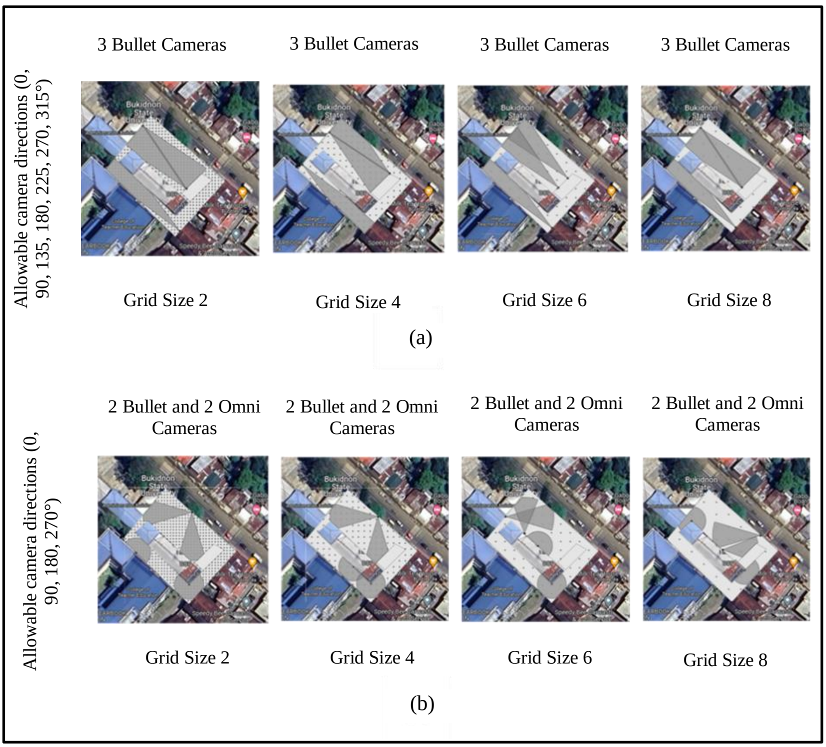


Figure 5. Strategic surveillance camera coverage layouts at BukSU with allowable camera directions (a) 0, 45, 90, 135, 180, 225, 270, 315 degrees and (b) 0, 90, 180, 270°

The target layout was divided into grids resembling a chessboard pattern, with varying sizes to test different levels of detail. Specifically, the layout was partitioned into grid sizes of 2 x 2 m, 4 x 4 m, and 8 x 8 m. Several important factors were considered in this process. The grid size was crucial as it determined the level of detail in the layout, with smaller grids providing more precise placement options. The sensor buffer refers to the buffer zones around potential camera positions, ensuring that cameras are not placed too close to each other or obstructions. The maximum and minimum distances between potential camera positions within these buffer zones help to maintain optimal spacing and coverage. The alpha number is another critical factor, representing how many directions each camera can face. For example, if cameras can be installed to face 0, 90, 180, and 270°, the alpha number is set to 4. This ensures that the cameras can be oriented in the most effective directions. Additionally, the coverage requirements specify the necessary extent of monitoring for each position. By considering these factors, the process allowed for a thorough analysis of how different grid resolutions and placement parameters affect the performance of the surveillance system. This methodology helped to identify the best configuration that balances effective coverage with cost efficiency, providing a robust framework for strategic camera placement in complex environments.

This cost-effective approach utilizes cameras with broader angles of view to minimize the total number needed. The fourth layout, similar to the third, employs cameras positioned to cover expansive areas with slight adjustments in placement and orientation, demonstrating how small changes can impact overall coverage and enhance system efficiency. These layouts highlight the importance of strategic camera placement in surveillance system design, balancing coverage and cost, and leveraging cameras with varying specifications to ensure optimal monitoring. By exploring different configurations, the BukSU grounds can be effectively monitored, ensuring the safety and security of students, faculty, and staff while meeting budgetary constraints. Table 2 displays four distinct configurations of surveillance camera placements at the BukSU grounds captured via Google Satellite. The images highlight various strategies for optimizing camera coverage with a focus on cost-effectiveness, specifically utilizing bullet and omni cameras

Table 2. Cost analysis of surveillance camera configurations

Alpha number	Grid setting	Quantity of cameras	Type of camera	Approximate cost (Php)	Total cost (Php)	Grid pattern
Allowable Camera directions (0, 45, 90, 135, 180, 225, 270, 315) degrees	2	3	2 B5	4,200	8,400	Dense grid
			1 B6	4,200		
	4	3	2 B5	4,200	8,400	Moderately dense grid
			1 B6	4,200		
	6	3	2 B5	4,200	8,400	Moderate grid
			1 B6	4,200		
	8	3	2 B5	4,200	8,400	Sparse grid
			1 B6	4,200		
Allowable Camera directions (0, 90, 180, 270) degrees	2	4	1 B3	3,540	13,140	Dense grid
			1 B4	3,840		
			2 O1	2,880		
	4	4	1 B3	3,540	13,140	Moderately dense grid
			1 B4	3,840		
			2 O1	2,880		
	6	4	1 B3	3,540	13,140	Moderate grid
			1 B4	3,840		
			2 O1	2,880		
	8	4	1 B3	3,540	13,140	Sparse grid
			1 B4	3,840		
			2 O1	2,880		

3.2 Dense Grid Pattern

In the dense grid layout, where allowable camera directions are set at (0, 45, 90, 135, 180, 225, 270, and 315°), the analysis showed that despite increasing the grid density, the number of cameras and types used remained consistent. Across all grid settings, the configuration employed two bullet B5 cameras and one bullet B6 camera, resulting in a stable total cost of Php 8,400.00. This suggested that the wide range of allowable directions ensured that the cameras covered all areas adequately without requiring additional units as density increases. While this layout provideed comprehensive coverage, it did so at a fixed cost, making it an efficient solution for environments that can afford to maintain the same level of camera density across various zones

3.2.1 Moderately Dense Grid

For the moderately dense grid, where the allowable camera directions are limited to (0, 90, 180, and 270°), a different trend was observed. As the grid density increased, the layout consistently integrated both bullet and omnidirectional cameras, with an additional bullet camera added to accommodate the increased density. This change resulted in higher costs as the grid density increases. In this configuration, one bullet B3 camera, one bullet B4 camera, and two omnidirectional o1 cameras were employed, resulting in a total cost of Php 13,140.00. This indicated that while the moderately dense grid balanced coverage and cost, the need for extra cameras due to limited directional flexibility resulted in higher costs as grid density increased. The integration of omnidirectional cameras with wide-angle views still contributed to cost efficiency, but the additional bullet cameras raise the total expenditure.

3.2.2 Wide Angle Coverage

The wide-angle coverage layout leveraged the broader field of view provided by omnidirectional cameras. Table 2 highlights the consistent integration of omnidirectional cameras across all grid patterns for allowable camera directions (0, 90, 180, and 270°), showcasing their critical role in achieving effective surveillance. In dense grids (e.g., 2-m settings), the system employed one bullet B3, one bullet B4, and two omnidirectional (O1) cameras, ensuring focused monitoring of key areas while providing broad, 360° coverage. This configuration achieved comprehensive surveillance at a total cost of Php 13,140.00. In moderately dense grids (4-m settings), the same camera setup maintained robust coverage with the same cost, balancing placement flexibility and coverage efficiency. As the grid became sparse (e.g., 8-m settings), omnidirectional cameras were vital in addressing limited placement opportunities. Their wide field of view compensated for the reduced density, ensuring consistent and effective coverage across expansive areas. Omnidirectional cameras enhanced adaptability and cost-efficiency across all grid patterns, complementing the targeted capabilities of bullet cameras. Their inclusion minimized blind spots and ensured comprehensive coverage, making this configuration highly effective for large, open-field environments like university campuses.

3.2.3 Optimized Camera Positioning

The optimized camera positioning layout further enhanced cost efficiency by making slight adjustments to the placement and orientation of both bullet and omnidirectional cameras. By strategically refining camera placement, this layout minimized blind spots and ensured comprehensive coverage without increasing the number of cameras. Like the wide-angle coverage layout, the total cost for optimized positioning was around Php 13,140.00, but it achieved more efficient monitoring by fine-tuning the placement of each camera. This layout provided the most cost-effective solution, combining extensive surveillance coverage with minimal additional expenditure. It offered a scalable and flexible approach to securing large university environments while adhering to budget constraints.

3.3 Impact of Grid Density and Allowable Camera Directions on Camera Configuration and Costs

An in-depth analysis of camera configurations under varying grid densities and two distinct sets of allowable camera directions revealed how both factors significantly influenced the number of cameras required and the overall costs of surveillance systems. In scenarios using a dense grid pattern – smaller grid sizes like 2 m, resulting in more potential camera placement points – configurations greatly benefit from the flexibility offered by an extensive set of allowable camera directions. With cameras oriented at every 45° (0, 45, 90, 135, 180, 225, 270, and 315°), the system can achieve optimal coverage with a minimal number of cameras. Specifically, these configurations consistently employed two bullet B5 cameras and one bullet B6 camera, maintaining a stable total cost of Php 8,400. This stability resulted from the dense grid's precise camera placement and the extensive allowable orientations that enabled each camera to cover more area effectively. The finer granularity allowed cameras to be positioned optimally to maximize their fields of view. Adjusting camera orientations at every 45° further enhanced coverage by precisely targeting areas that needed monitoring, reducing blind spots and overlaps. Consequently, even as the grid became denser, there was no need to add more cameras, keeping costs consistent while maintaining comprehensive coverage.

Conversely, with a less dense grid – larger grid sizes like 6 or 8 me – the number of potential camera placement points decreased significantly. If allowable camera directions were limited to every 90° (0°, 90°, 180°, and 270°), the system faced additional constraints. The coarser grid reduced flexibility in camera placement, making optimal positioning challenging. The restricted orientations limit the ability to adjust camera angles to cover specific areas effectively, leading to potential blind spots and inadequate coverage. To compensate for these limitations, the surveillance system required additional cameras to achieve the desired coverage. For instance, in less dense grids with limited camera directions, configurations may need to employ four or more Bullet cameras instead of the three used in the dense grid scenario. Each additional camera added to the total cost – not only in purchase price but also in installation and maintenance expenses. This increase led to higher overall costs, especially as the grid became less dense, and orientation options remained limited.

Integrating a dense grid with an extensive set of allowable camera directions significantly enhanced both coverage efficiency and cost-effectiveness. The finer granularity offered more placement options, enabling cameras to be strategically positioned at precise locations to maximize their coverage areas. The extensive allowable orientations allowed cameras to be angled accurately toward specific regions, ensuring that critical areas were monitored without unnecessary overlaps or gaps. This combination reduced the need for additional cameras, maintaining stable costs even as grid density increases.

In contrast, less dense grids with limited allowable camera directions constrained both placement and orientation flexibility. The reduced number of potential camera locations and restricted camera angles necessitated deploying more cameras to cover the same area adequately. This approach led to increased costs and may still result in less optimal coverage compared with configurations using denser grids and more flexible orientations.

4. Conclusion and Recommendation

This study focused on optimizing CCTV camera placement for large-scale environments, using BukSU as a case study. Analyzing various grid configurations and camera layouts, the research found that employing a dense grid pattern with flexible camera orientations was the most effective strategy for maximizing surveillance coverage while maintaining stable costs. The increased granularity of a dense grid allowed for finer camera placement options, enabling optimal positioning without the need for additional cameras. This approach enhanced coverage efficiency by allowing cameras to be precisely placed and oriented to cover critical areas, reducing blind spots and overlap.

In contrast, less dense grids with limited camera orientations increased costs because additional cameras were needed to achieve the desired coverage. The coarser grid lacked the flexibility to select finer camera locations, and restricted camera orientations limited placement options. As a result, more cameras were required to cover areas that could have been monitored by fewer cameras in a denser grid, leading to higher overall expenses. The study also demonstrated that integrating both bullet and omnidirectional cameras, along with strategic placement adjustments, resulted in the most efficient configuration. By combining the strengths of both camera types and making minor adjustments in placement and orientation, comprehensive monitoring was achieved without incurring additional costs.

However, the study has limitations, as the analysis was based on simulations and theoretical models without real-world implementation. Factors such as environmental conditions, physical obstacles, and human behavior – which could affect camera performance and coverage – were not extensively explored. Additionally, the focus was solely on initial installation costs, without considering long-term maintenance expenses or potential technological advancements that could impact cost and efficiency. Based on these findings, it is recommended that institutions adopt dense grid configurations with flexible camera orientations to maximize coverage efficiency while maintaining stable costs. Implementing dense grid patterns with smaller grid sizes maximizes placement flexibility. Allowing cameras to be oriented at multiple angles, such as every 45°, enhances the ability to cover areas precisely, reducing the need for additional cameras. Strategically integrating bullet cameras for focused monitoring of specific areas like entry points and high-risk zones with omnidirectional cameras for wide-area coverage ensures comprehensive surveillance. This integration leverages the strengths of both camera types, minimizing blind spots and enhancing overall security without increasing expenses.

Future projects should include practical testing of the proposed configurations under actual environmental conditions. Real-world implementation will provide valuable data to refine placement strategies, address factors such as physical obstacles and lighting conditions, and validate the effectiveness of the optimized layouts. Organizations should also consider long-term maintenance costs when planning their surveillance systems. Staying informed about technological advancements, such as artificial intelligence for dynamic camera positioning and automated monitoring, can further enhance effectiveness and cost-efficiency. Incorporating these technologies may lead to improved system performance and adaptability. Institutions should tailor their surveillance systems to their unique environments and security requirements. Assessing high-risk areas, traffic patterns, and specific security concerns allows for informed decisions on camera placement and system design. This customization ensures that security measures are both effective and aligned with budget constraints.

Implementing these recommendations can help institutions optimize their surveillance systems, achieving maximum coverage with minimal costs. By adopting dense grids with flexible camera orientations and strategically integrating different camera types, organizations can enhance coverage efficiency and maintain stable expenses. Real-world testing and consideration of long-term factors will further refine these systems, ensuring they remain effective over time. The insights from this research contribute to the broader field of surveillance optimization, offering practical guidelines for securing large, open environments effectively. This study provided a viable solution for BukSU and served as a model that can be adapted by other universities and large institutions facing similar surveillance and security challenges.

5. References

Altahir, A.A., Asirvadam, V.S., Hamid, N.H.B., Sebastian, P., Saad, N.B., Ibrahim, R.B., & Dass, S.C. (2017). Optimizing Visual surveillance sensor coverage using dynamic programming. IEEE Sensors Journal, 17(11), 3398-3405. https://doi.org/10.1109/JSEN.2017.2694385

Contreras, M., Freitas, R., Ribeiro, L., Stringer, J., & Clark, C. (2017). Multi-camera surveillance systems for time and motion studies of timber harvesting equipment. Computers and Electronics in Agriculture, 135, 208-215. https://doi.org/10.1016/j.compag.2017.02.005

Golparvar-Fard, M., Heydarian, A., & Niebles, J.C. (2013). Vision-based action recognition of earthmoving equipment using spatio-temporal features and support vector machine classifiers. Advanced Engineering Informatics, 27(4), 652-663. https://doi.org/10.1016/j.aei.2013.09.001

Hamledari, H., McCabe, B., & Davari, S. (2017). Automated computer vision-based detection of components of under-construction indoor partitions. Automation in Construction, 74, 78-94. https://doi.org/10.1016/j.autcon.2016.11.009

Han, Z., Li, S., Cui, C., Song, H., Kong, Y., & Qin, F. (2019). Camera planning for area surveillance: A new method for coverage inference and optimization using location-based service data. Computers, Environment and Urban Systems, 78(August), 101396. https://doi.org/10.1016/j.compenvurbsys.2019.101396

Li, H., Yang, X., Skitmore, M., Wang, F., & Forsythe, P. (2017). Automated classification of construction site hazard zones by crowd-sourced integrated density maps. Automation in Construction, 81(April), 328-339. https://doi.org/10.1016/j.autcon.2017.04.007

Suresh, M.S.S., Narayanan, A., & Menon, V. (2020). Maximizing camera coverage in multicamera surveillance networks. IEEE Sensors Journal, 20(17), 10170-10178. https://doi.org/10.1109/JSEN.2020.2992076

Walton, A.L.J., DeVaney, S.A., & Sandall, D.L. (2012). Graduate students' perceptions of privacy and closed-circuit television systems in public settings. In A. Mesquita (Ed.), User perception and influencing factors of technology in everyday life (pp. 107-127). Pennsylvania, United States: IGI Global Scientific Publishing.

Yang, X., Li, H., Huang, T., Zhai, X., Wang, F., & Wang, C. (2018). Computer-aided optimization of surveillance cameras placement on construction sites. Computer-Aided Civil and Infrastructure Engineering, 33(12), 1110-1126. https://doi.org/10.1111/mice.12385