ISSN No- 2584-2706

Optimizing Cctv Camera Placement for Campus Security: A Binary Integer Programming Approach for Clemson University

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Abstract

The quest for optimal camera placement for effective surveillance has long been an academic pursuit. However, the advent and proliferation of visual sensor networks have propelled this issue into the practical realm, necessitating solutions that are both viable and implementable. The complexity of formulating camera placement as a binary integer programming (BIP) problem, despite its adaptability, often leads to NP-hard scenarios, which present significant challenges for achieving exact solutions, particularly for large-scale applications. This study introduces a binary integer programming technique to strategically minimize the number of CCTV cameras while ensuring adequate surveillance coverage, with a particular focus on the Clemson University campus. Using integer linear programming (ILP), our approach overcomes the traditional hurdles associated with BIP. By constructing a systematic model that leverages the predictability of ILP, the paper demonstrates a method that is both computationally manageable and accurate in deducing the minimum number of cameras needed for full coverage. In operationalizing this model, the study made certain assumptions about the Clemson University campus street layout. It was presupposed that the average length of each street segment was known, and the fields of view for camera installation were predefined. A key presumption was that cameras should be stationed at every road intersection, capturing two street perspectives. This strategy ensures that each street segment is monitored by at least one camera. From this analysis, it was inferred that an optimal, minimal number of cameras could be strategically placed at various key points to provide comprehensive surveillance coverage. This inference is crucial, as it aligns with the objective of deploying a surveillance system that is not only effective but also economical and efficient in its use of resources. This methodology significantly advances the practical deployment of surveillance systems, particularly in complex and expansive settings, where the intricate interplay of coverage areas, camera fields of view, and the necessity for minimization of resources is paramount. The proposed model promises a sophisticated yet practical solution to the pervasive challenge of security surveillance, marrying theoretical rigor with practical application.

Introduction

The protection of individuals at universities has emerged as a crucial priority over the past decade because of advancing dangers and insecure conditions. However, owing to their extensive size, multiple access points and high population density, university spaces are particularly problematic in relation to questions of surveillance and securitisation. To deal with these challenges, the use of Closed Circuit Television Cameras that are Cathy has been as one of the most effective measures in enhancing safety in the compound by preventing any crime that may occur in the compound through the cameras (Piza et al., 2019). This project aims at increasing security in Clemson University by placing more cameras in areas of visibility in the whole campus. The project also aims to locate the maximise surveillance coverage at the least number of CCTV cameras using ILP methods. This approach is very important because it helps in the economical use of resources without compromising a lot on security within this compound. The campus itself – the Clemson University covers a large area that measures 171 streets, and to implement this system successfully, much thought was needed to come up with the best way to install the cameras to be able to cover as much area as possible with as few cameras as possible. Well-planned camera installation is crucial for minimizing expenses but also for virtually eliminating blind spots and for achieving most-encompassing coverage (Zhao & Yoshida, 2018). PTZ CCTV cameras for instance have been recently adopted on account of their flexibility in use as compared to other standard cameras. PTZ cameras enable operators to move the cameras

horizontally, vertically or zoom, which means

more area is covered and the event is recorded live from all angles (Lai, Sheu, & Lu, 2018). Due to its capacity to constantly pan and tilt while zooming to keep watch over expansive regions, PTZ cameras would be suitable for faculties of universities. These cameras provide high-resolution imagery, which is essential for identifying incidents or suspicious activity, and offer the flexibility to adjust to changing surveillance needs.

In this project, the strategic use of PTZ cameras ensures that large sections of Clemson University's campus are monitored effectively without the need for an excessive number of cameras. This not only enhances security coverage but also promotes efficiency in resource allocation. The cameras can watch over extensive areas, adjusting their focus and angle to track movements, which is especially useful for capturing unexpected events or monitoring crowded areas. For example, a single PTZ camera installed at a busy intersection could monitor traffic flow, pedestrian activity, and potential security threats simultaneously (Chen & Davis, 2013).

By combining advanced camera technology with optimization techniques like ILP, this project ensures that Clemson University remains a safe environment for students, staff, and visitors. The project also highlights the importance of leveraging technology in modern security management, demonstrating how mathematical modeling and surveillance technology can work together to provide practical solutions to real-world problems (Altahir et al., 2019). This approach could serve as a model for other universities and large institutions facing similar challenges in managing security over extensive areas.

Figure 1: Example of a PTZ CCTV camera planned for the university's security system.

fig1.PTZCCTVCamera(PhotoCredit:www.change-congress.org)

Aim

The aim of this study is to develop an optimal CCTV camera placement strategy for Clemson University using a binary integer programming approach. The goal is to maximize campus surveillance coverage while minimizing the number of cameras required, ensuring efficient resource allocation and enhanced campus security.

Objectives

1. To identify key areas of surveillance on Clemson University's campus where CCTV cameras should be placed for maximum coverage, including access points, intersections, and high-traffic zones.
2. To formulate a binary integer programming (BIP) model to minimize the number of CCTV cameras while ensuring that all critical areas are covered.
3. To analyze the field of view (FOV) for each camera and its ability to cover specific road segments and campus areas, ensuring no blind spots.

Limitations

1. Assumptions in Road and Campus Layout: The model assumes that the campus street layout and building configurations are static, but changes in infrastructure or temporary structures could affect the camera coverage and placement.
2. Limited Camera Types: The study focuses on Pan-Tilt-Zoom (PTZ) cameras, and the findings may not be directly applicable to other camera types with different technical specifications or capabilities.
3. Environmental Factors: The model does not account for environmental factors such as lighting conditions, weather, or obstructions (e.g., trees, construction) that may affect camera performance.
4. Simplified Surveillance Zones: For the sake of computational efficiency, certain areas such as peripheral streets or less critical zones may be excluded from the analysis, potentially leaving gaps in coverage.
5. Computational Complexity: The binary integer programming (BIP) approach may become computationally expensive and challenging to solve for larger campuses or environments with more complex layouts.
6. Cost of Implementation: While the model focuses on minimizing the number of cameras, it does not account for installation costs, maintenance, or the potential need for additional equipment like monitoring stations or storage solutions for footage.

Literature Review

The case of positioning and orienting CCTV cameras for surveillance has been developed quite extensively in the theoretical literature as well as in many practical contexts. Various strategies have been put forward, all intended to enhance coverage and reduce the number of cameras needed. However, a common problem with most of the approaches is that it becomes difficult to do the areas at reasonable cost without compromising on coverage. Dynamic Programming Approach Dynamic programming was studied in the mathematical optimization of the coverage of a camera network by Altahir et al. (2019). At present, their approach tackles planned locations of the camera and tries to increase coverage by choosing effective positions within the given set of points. While dynamic programming is effective for varying camera positioning, the paper does not consider the question of how many cameras to use, which is a crucial factor in cost efficiency in large scale systems. In the real world, the practice of predefining the area for camera positioning might be hardly possible at all, especially within the P buckets like university campus as far as spatial distribution and security are concerned. Minimization and Maximization Problems On the other hand, Zhao and Yoshida (2018) studied different methods for positioning the cameras with reference to the minimization and maximization concerns. Their study distinguishes between two primary goals: from decreasing the number of cameras and expanding the coverage that exists with a specific number of cameras. The authors comment that both goals pose the challenge of design since coverage and minimization of the number of cameras demands much computational power. This makes their approach less desirable for large scale applications, such as extended university grounds, for example, where it becomes more of a precedence to use efficient computational techniques.

High-Resolution Imaging and View Optimization

Bodor and Drenner (2021) addressed a different issue, namely the optimization of camera views for high-resolution imaging in variable environment. Their approach is convenient when it's needed to perform some specific surveillance tasks where detailed imagery is needed, for example, facial recognition or license plate identification. But their contribution does not help to solve the problem of how many of them are required to cover a given area, an essential parameter when creating efficient and low-cost surveillance systems. Although they are useful when it comes to optimizing image resolution, unfortunately, they do not speak to the problem of how best to position cameras for maximum coverage.

Error Estimation in Image Resolution for Tracking

Chen and Davis (2013) proposed a quality metric designed from the projected error estimate depending on image resolution in order to determine adequate camera positioning for the monitoring of moving objects. Their method centers around identifying areas in which cameras found the best combination of resolution and object tracking ability. Although this technique gives an idea of the quality of the surveillance videos, it fails to indicate the number of cameras needed for complete coverage. That is why their methodology, though correct for a particular application, is inefficient in terms of solving the essential problem – reducing the number of cameras used.

Key Limitations Across Studies

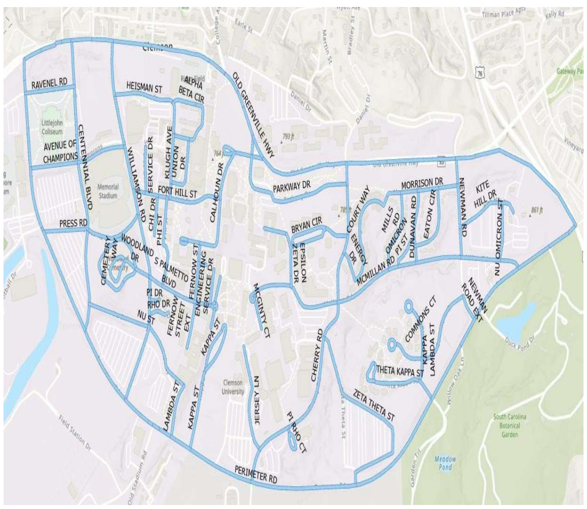
One common drawback found in the reviewed studies is that, when making decisions about the choice of cameras, the issue of reducing the total number of cameras is not effectively balanced against the question of achieving the required level of coverage. This factor is crucial because large scale identification such requires in universities should be efficient and cheap. Often this is achieved with relatively simple objectives – to meet equipment costs and ensure that the security provision is effective. While prior approaches may primarily concern efforts to increase coverage quality or to develop and upgrade certain modes of surveillance, there is a lack of general approaches that would address the problem of the optimal number of cameras to maintain extensive coverage of certain areas all-together. The availability of a model that will address the issue of either having many cameras or having the guarantee of capturing all areas of interest is highly demanded in formulating surveillance models that are financially feasible and workable.

Methodology

Data Collection and Analysis

The functional requirements of our security project revolve around identifying key surveillance zones such as perimeter areas and crucial access points. To achieve this, we began by obtaining a detailed map of Clemson University, which includes all 170 main streets and possible camera installation spots. This detailed map was sourced from ArcGIS Pro, and it shows the intricate layout of the campus roads.

For our analysis, we excluded certain streets that form the outer boundary of the university, simplifying our focus to the central areas where surveillance is most needed. For our CCTV setup, we selected PTZ (Pan-Tilt-Zoom) cameras, ensuring comprehensive coverage along the stretches of road they oversee. This expansive field of view is crucial for monitoring long distances without the need for multiple cameras in close succession. Figure 2 illustrates the road network of Clemson University obtained from



ArcGIS Pro data online.

Figure 2: Clemson University Road Network.

When setting up surveillance cameras, one key factor to consider is the camera's field of view (FOV), as illustrated in

Figure 3, which is the area that the camera can visibly capture at any moment.

It's crucial to calculate the FOV properly to make sure that it covers all the important areas for surveillance, leaving no blind spots. By working out the FOV of the cameras, we can use linear integer programming as a solid method for figuring out where to put cameras, how many the school might need, and the angle needed to ensure maximum coverage area.

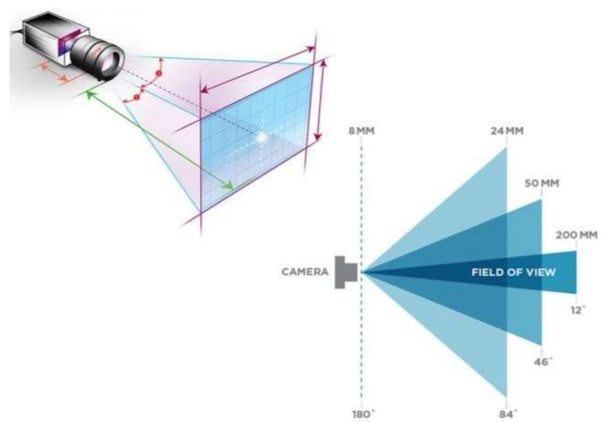
To ensure clear footage from a wide distance, we have made some assumptions about the average street length and used these to calculate the camera coverage area. For a clear standard image, the table below shows the camera properties which were used.

CCTV Camera properties

Sensor Width	4.8mm
Sensor height	3.6mm
Focal length	50mm
Angle of view	46deg

Figure 3 Field of view by the CCTV.

Problem Formulation



The goal is to optimize the placement and orientation of CCTV cameras on a road layout grid to maximize the coverage area of a university campus. The cameras will have a fixed angle of view (AOV) but can be oriented in several directions.

Steps:

1. Define a Grid Layout:

Create a grid representation of the university campus road network where cameras can be placed, and their coverage can be analyzed.

2. Decide the Number of Rows (n) and Columns (m):

Divide the campus into a grid based on the size of the campus and the desired granularity of coverage.

3. Set the Possible Orientations for the Cameras:
This would be in degrees and can cover a full 360-degree range, with a 45-degree interval.

4. Define the Angle of View:
This determines how wide the cameras can see, typically 46 degrees, with a focal length of 50mm.

5. Create a Function:
Develop a function that loops through all the possible camera positions (i1, j1) and orientations.

6. Check Field of View (FOV):
For each position and orientation, create another function to check which grid cells (i2, j2) are within the field of view (FOV), both

$$max \sum_{i_1} \sum_{j_1} \sum_{\theta_1} \sum_{i_2} \sum_{j_2} m_{i_1 j_1 \theta_1} \cdot \varepsilon_{i_1 j_1 \theta_1 i_2 j_2}$$

$$1 \le i \le n$$

$$1 \le j \le m$$

$$0 \le \theta \le 360$$

$$s_k = k^{th} \text{ segment of road or monitored area}$$

horizontally and vertically.Formula for Field of View (FOV)**:**

Horizontal FOV= $2 \times \arctan\left(\frac{sensor\ width}{2 \times focal\ length}\right)$

VerticalFOV= $2 \times \arctan\left(\frac{sensor\ height}{2 \times focal\ length}\right)$

1. The final step is to run the Genetic Algorithm to compute the total coverage area based on the placement and orientation of the camera.
   - Initialize a matrix (coverage area matrix)
   - If a grid cell is within the field of view of a camera, mark it as covered in the coverage matrix.
   - Sum the values in the coverage matrix to get the total coverage area.

Mathematical Formulation
DecisionVariables:

- Let beabinaryvariablethatindicatingacam eraplacementatgrid cell $(i, j)$with orientation θ.

$$\varepsilon_{i_1 j_1 \theta_1 i_2 j_2} = 1 \text{ if cell } (i_2, j_2) \text{ is visible from camera location } (i_1, j_1) \text{ with orientation } \theta_1$$

ObjectiveFunction:
Maximizingthetotalweighteffectivecoverage area:

Constraints:

1. Coverage Constraint: Ensure that each stretch of road (j) is covered by atleast one camera:

$$\sum_{\theta} m_{ij\theta} \le 1 \quad \forall_{(i,j)}$$

2. Coverage for each campus road

$$\sum_{(i,j) \in s_k} \sum_{\theta} m_{ij\theta} \ge 1$$

3. Locationand Orientation Bound

Horizontal width = (6.4 millimeters × average street distance) / focal lens (5 millimeters) = **198.976 feet**

Vertical width = (4.8 millimeters × average street distance) / focal lens (5 millimeters) = **149.23 feet**

The camera will now have a coverage area of **75.84 feet at 79 feet**.

It was assumed that each camera has the same coverage area for all areas and locations. With this, we concluded that if every street is to have at least one CCTV camera, it will be good enough to provide an accurate view and better footage.

Imager Size	⅓ inch	½ inch	⅔ inch
Horizontal Format	4.4 millimeters	6.4 millimeters	8.8 millimeters
Vertical Format	3.3 millimeters	4.8 millimeters	6.6 millimeters

Figure 3: Standard image sizes

The key objective was to minimize the number of CCTV cameras while ensuring that each of the 117 streets was adequately covered. The problem was formulated as an integer programming model. The primary constraint was that each main street must be within the surveillance range of at least one CCTV camera. **Figure 4** illustrates the road layout of Clemson University with the maximum locations where the CCTV cameras are to be placed. In all, a maximum of 80 locations were selected because the cameras were to be placed at the intersection of two roads. This constraint ensured that no area of the campus was left unmonitored.

Using integer programming techniques, the model identified the optimal number and placement of CCTV cameras. This involved an iterative process where different configurations were evaluated to find the most efficient layout that met all security requirements. Some road intersections, like the roads around the boundary of the university, were not considered. Roads like the Old Greenville Hwy and Perimeter Road were excluded because those roads are managed by the South Carolina Department of Transportation.

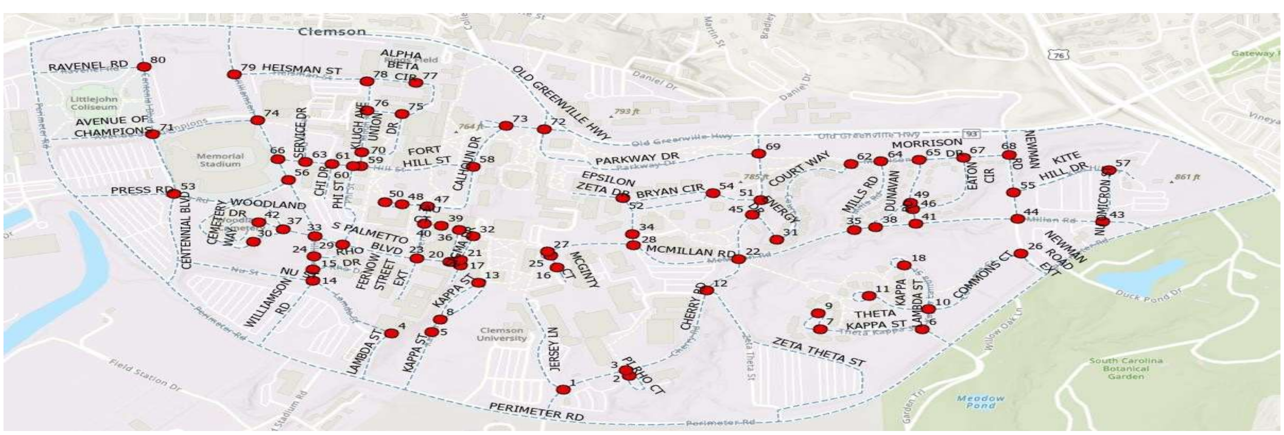
Figure 4: Road layout of Clemson University with locations where CCTV cameras will be placed.

Results

After meticulously constructing and solving the binary integer programming model through Excel's simplex algorithm, we have identified **43 optimal locations** that are ideal for the installation of CCTV cameras across the campus to maximize the total coverage area. These locations were chosen to enhance security and safety for all individuals on campus.

The map accompanying this text, referred to as the figure below, marks these optimal locations. It demonstrates a strategic spread of surveillance points, ensuring that each street is adequately covered by at least one camera, in accordance with the calculated field of view required for effective monitoring.

The optimization through the simplex method has not only guaranteed thorough surveillance but also has been instrumental in optimizing resources, thereby balancing campus safety with cost efficiency. The final selection of these locations signifies a significant stride in fortifying campus security infrastructure with a well-founded analytical approach.



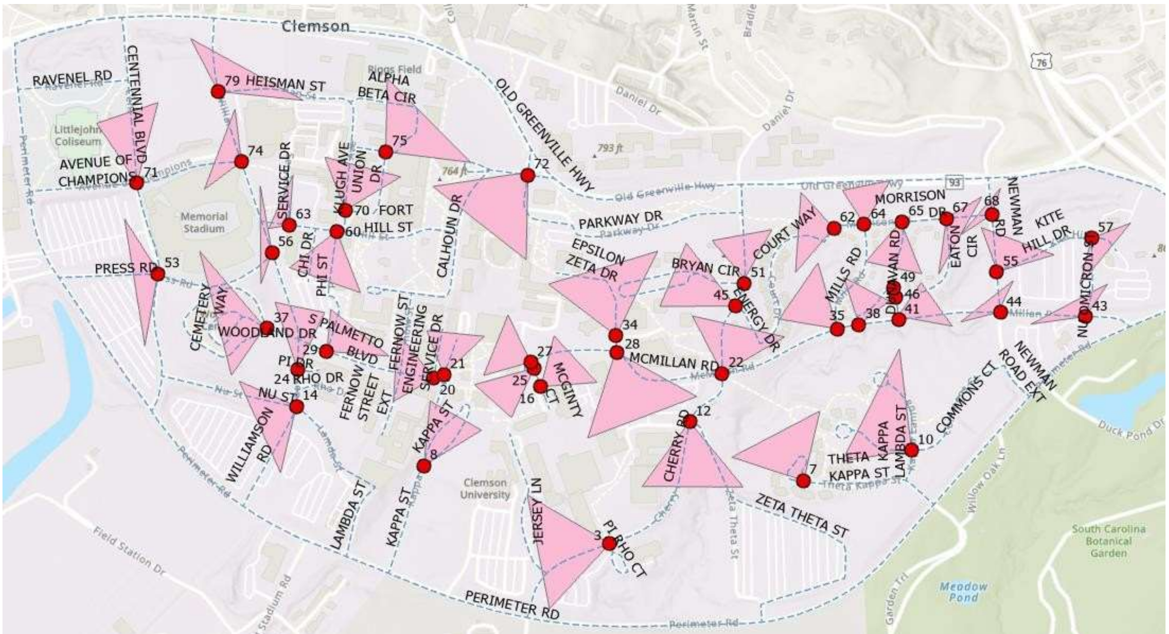


Fig.4 locations for the installation of CCTV cameras

Recommendation

This project showed us a practical way to use math and planning to make our campus safer. By figuring out the best places to put CCTV cameras, we made it easier to keep an eye on things, which helps everyone feel more secure. What we've done here could be used at other colleges too, proving that math isn't just about numbers; it's about solving real-life problems.

Looking ahead, we can think about how to cover areas with as few cameras as possible, which saves money and equipment. We can also think about how much it will cost to set everything up and try to keep that low. Another thing to consider is making sure the cameras can communicate with each other without any trouble. Lastly, we want to ensure the cameras can pinpoint where things are happening without making many mistakes. We are thinking about adding these ideas to our plan later, especially how to reduce errors when figuring out where something is based on the camera's turning angle.

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