Autonomous Visual Surveillance Operations

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1 Introduction & Motivation

Small scale surveillance operations are often complex problems that originate spontaneously and need to be addressed quickly. Instances in which public safety is at risk and large swaths of areas must be patrolled occur frequently in societal functions, the most prevalent on academic campuses is the tailgating of university athletic functions. These events require law enforcement presence as an emergency response force, however their capabilities are limited. Drone deployments with visual capabilities have been explored as potential alternatives to human intervention, garnering interest through the promise of faster deployment times, removal of risk to human agents, and superior investigative prowess. However, due to the high variability inherent to a spontaneous surveillance operations, such an autonomous system has not been deployed or explored as a potential solution.

Given that these types of surveillance operations frequently occur on public areas, with known environmental elements such as buildings, roads, waterways, and grass areas any such surveillance strategy must take these elements into account, either as areas of interest, or as obstacles of observation. To this end, these environmental elements are an integral part of any formulation and will play a key role in defining the areas of interest; the areas in which we would like to conduct a surveillance operation, as well as the constraints that dictate from which locations we are able to effectively observe those points of interest from an aerially deployed drone.

We were inspired by the work of C. Christodoulou and P. Kolios in their paper Optimized Tour Planning for Drone-Based Urban Traffic Monitoring where they examined a Vehicle Routing Problem (VRP) that sought to determine optimal tours of drones that observed points of interest along road ways in Cyprus, Italy. They were concerned with constraints pertaining to line of sight capabilities of drones as they traversed the proposed tours. As such, they determined which target locations could be viewed from which surveillance positions and generated their tours having ensured the integrity of the surveillance operation would be intact. Given the set of locations to be visited, the aim becomes to compute optimized tour plans that minimize the number of drones necessary to cover the target area, considering limitations of drones and their flight times.

Building on this work, we would like to focus in greater detail on the constraints associated with line of sight surveillance through drones, and the categorization/selection of target locations to be surveyed. The general pipeline of this project is to define an area of interest that you would like to conduct an aerial surveillance operation of, collect some set of images of this area (satellite images, traffic layers, terrain layers, or other descriptive layers that designate characteristics of interest), apply a pixel value mask to these images,and sample the remaining points to determine the locations of interest known as targets. Over this same area, an aerial grid of surveillance locations are generated as potential locations for a drone to travel to and observe the targets. From these Location - Target pairs, data from public building and landscape databases is pulled and tested to determine if the targets can be visually observed from the surveillance locations.

Once this matrix of Location - Target pairs is generated, a set covering problem is able to be defined in which we seek to select a subset of aerial locations with which all target locations are observed, while also minimizing the distance value of the resulting tour of these Locations. This optimization problem returns a set of nodes that function as a minimal distance tour for our drone.

The pipeline and implementation of this process is explained in greater detail in an associated Jupyter notebook.

2 Problem Definition & Formulation

Our problem deals with a user defined area of interest, in our case we defined this area as SUNY University at Buffalo North Campus. This area is captured using satellite image maps or traffic/zoning areas, and is defined by the latitude-longitude coordinates of North West and South East corner points. These points define the inputs of the masks that are then used to isolate the features of interest that we would like to survey. In our case, we sought to examine green spaces and roadways/parking lots. The filters applied by the masks gave us the set of points from which we sampled ground points to survey, and using the defined lat-lon corner points we generated a grid of aerial points. With these two sets we are able to define the optimization model used by Christodoulou and Kolios.

2.1 Min Size Set Covering Formulation

Let T be defined as the set of Targets, $T = \{1, 2, ..., n\}$

Let L be defined as the set of Locations, $L = \{1, 2, ..., m\}$

Let matrix $\mathcal{C}_{i,j} \in \{0, 1\}$ be defined as the matrix representing weather there exists a line of sight (LOS) from location $l_j \in$ L to target $t_i \in$ T where 1 indicates that there is a LOS and 0 if there is not an LOS

Let the decision variable $x_j = 1$ if a sensor is placed at j, 0 otherwise

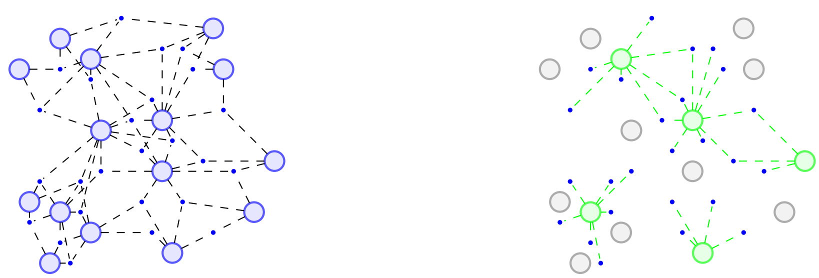
The placement problem can then be defined using the formulation below:

$$\min \quad \sum_{j \in M} x_j \tag{1}$$

$$s.t. \quad \sum_{j \in M} \mathcal{C}_{i,j} x_j \geq 1 \qquad j \in M \tag{2}$$

$$x_j \in \{0, 1\} \qquad j \in M \tag{3}$$

This formulation generates a set of surveillance location nodes which when applied to a surveillance operation generates a tour of minimal size that still surveys all target locations. This can be visualized as a biparte graph, where the selected surveillance nodes are a cover for the target locations. This visualization is given below to demonstrate the concept.



(a) Original instance

(b) Valid cover $\mathcal{C}$

Figure 1: Given an instance of $< T, L >$ a valid cover $\mathcal{C}$ is proposed

3 Improvements of Previous Work

In our project, we built on the ideas presented by Christodoulou and Kolios, and our major areas of work are in the areas of obstruction calculations, and generality of applications. Christodoulou and Kolios used simple metrics of building heights and distances from roads to determine what surveillance locations would be able to see what points of interest on the ground. Instead of general calculations based on the tallest buildings in the area, we gathered specific building information based on the footprints and heights of buildings in the area from Open Street Map. Using this data we then calculated if any of these buildings obstructed the line of sight between our surveillance locations and the target locations. This allows for more accurate results where users can truly know if there is an obstruction. Additionally, our model allows for the surveillance of more locations, where as previous works were restricted to road networks. Users can define their areas of interest to be whatever they would like, be it waterways, green spaces, buildings, roads, sidewalks, etc. Finally, our models allow for greater customization of parameters, such as how many target locations there are, how they are distributed, and where the area of interest is located.

4 Future work and improvements

In the future, we would like to automate this process to improve the user experience and increase usability of this tool for wider applications. Creating an interface in which a user selects an area of interest, sets a mask based on their own criteria for what is important in their usage, determining the density of their aerial coverage grid, and the number of nodes belonging to each set of ground and aerial locations would all be within the control of the user.

We would also like to physically implement the tours generated from our models in drones to see the tours in action and verify that our results, when implemented, show the areas we expect them to. We hope to deploy these tours in the SOAR lab at a scaled version to test robustness.