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Evolutionary Approaches for Resilient Surveillance Management

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***Abstract*—The efficient management (placement and orientation) of security cameras within a floor plan is a well-known and difficult problem that has gained attention recently. The objective is to locate the minimum number of cameras in the space to ensure all walls are within the view of at least one camera. Heuristic-based approaches have been developed for this $\mathcal{NP}$-hard problem; unfortunately, most are only applicable to static situations. In modern applications, surveillance management must be resilient, and adapt if the environment changes.**

This paper introduces evolutionary-based approaches for active surveillance camera management. Using an evolutionary-based approach, a surveillance configuration (camera locations and orientations) is encoded as a chromosome and evolutionary processes are applied to identify better solutions over successive generations. The approach has the ability to identify efficient surveillance configurations (minimum number of cameras with maximum coverage); however, another advantage is the ability to adapt if the environment unexpectedly changes. Simulation results demonstrate this type of approach can manage surveillance cameras under dynamic conditions such as camera loss and the introduction obstacles better than traditional search methods.

***Index Terms*—surveillance systems; security; cameras; resiliency; art gallery problem; genetic algorithm;**

I. Introduction

The availability of low cost cameras and the growing demand for surveillance applications has renewed the interest in how to best manage camera-based surveillance systems [9]. For example surveillance systems can be used to improve the security of an industrial complex or to detect accidents within a manufacturing site [9]. Given the low cost of cameras there are possibly thousands of cameras available at a site; however, only a small set of cameras is actually needed to view (cover) the locations of interest. The management objective is to maximize the coverage (ensure locations of interest are under surveillance) while minimizing the number of cameras in use. Coverage is important to achieve the operational goal of the system (e.g. deter crime), while minimizing the number of cameras reduces energy consumption, which is especially important if batteries are in use.

The problem of determining the location and orientation of cameras to cover a polygon space was first introduced by Victor Klee in 1973 [8]. This original problem was known as the Art Gallery Problem (AGP) and sought to locate guards (cameras) in an art gallery such that every interior wall was observed by at least one guard. Algorithms exist to identify camera locations and orientations (cameras are typically located at the polygon interior vertices); however, finding the minimum number of cameras to provide coverage has been proven to be $\mathcal{NP}$-hard [7]. Since AGP was originally introduced, several variations of the problem have been proposed. Most are equally as difficult as the original, but are perhaps more applicable to a realistic situation. Given the proven difficulty of AGP, several heuristic-based approaches have been proposed. For example in [1], the floor plan, which is know in advance, is partitioned into smaller polygons and cameras are located within these smaller pieces. While many of these approaches provide good solutions to AGP-type problems, most assume the environment is static. In more modern application, it is expected that cameras will be added or removed for various reasons (e.g. unexpected failures). In addition, obstacles may appear and disappear at random times (e.g. cart moving through a warehouse). As a result, these approaches must recalculate solutions based on the new environment, which may be computationally expensive.

This paper investigates the use of evolutionary algorithms for managing cameras within a polygon space. An evolutionary approach can identify good solutions and adapt if the environment changes. Assume a set of cameras is located, perhaps randomly, within a polygon space. The location of each camera is fixed, but each can swivel 360 degrees to point towards any direction. Therefore this AGP variation seeks to determine the minimum set of cameras to use (turn on or off) and their orientation (swivel position) to maximize the wall cover. The approach encodes the on/off and swivel for each camera as a chromosome, then applies a series of evolutionary processes to find better solutions over successive generations (iterations). Simulation results with 40-sided polygons show the approach can identify good solutions under static and dynamic conditions. The continual searching nature of the approach allows the identification of good solutions if cameras are added or removed, as well as if obstacles are introduced in the space.

The remainder of this paper is structured as follows. Section II discusses surveillance management problems and the specific problem variation addressed in this paper. Evolutionary algorithms, fitness, and processes are reviewed in Section III. Simulation results of dynamic surveillance environments are

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discussed in Section IV, while Section V reviews the paper and discusses some future areas of research.

II. Surveillance Management

Surveillance management seeks to identify the location and orientation of cameras within a space such that all interested/targeted areas within that space are always observed by at least one camera. As described in the Introduction, this is similar to the Art Gallery Problem (AGP) which sought to place guards within a floor of a museum to ensure all walls are watched. The objective, which can be difficult to achieve, is to find the minimum number of cameras required for coverage (observe the targeted areas). The number of cameras that is always sufficient has been loosely bounded; however, this is not necessarily the minimum number [8].

For this paper, assume the polygonal space is initially populated with cameras, where each camera has the same view angle α. The camera locations can determined via an algorithm (based on a grid layout) or be random within the space as done with smart dust devices [3]. Although the camera locations are predetermined, every camera has the ability to swivel 360 degrees about their location. Let the specific orientation angle for camera i will be β_i. Furthermore, each camera has a binary activation state a_i that indicates if the camera is turned on or off; therefore, each camera i has two configuration settings (a_i, β_i). A surveillance configuration s is then a list of camera settings, one per camera, within the polygon space. In the example given in Figure 1, the surveillance configuration for the three cameras A, B, and C would be $s = \{(1, \beta_A), (0, \beta_B), (1, \beta_C)\}$. Note camera B is not activated in this example.

A. Surveillance Objectives

The objective of this problem is to find surveillance configurations that maximizes the wall coverage using the minimum number of cameras, and as a result is considered a multi-objective problem [2]. The management approach must determine which cameras to activate (a_i state) and their orientations (β_i angle). This problem is similar to the AGP variant called the Floodlight Set Problem (FSP) [8], where floodlights are positioned to ensure the maximum wall space is covered. The additional requirement for proper surveillance management considered in this paper is to constantly maintain maximum coverage using the minimum cameras as the environment changes.

As described in the Introduction, a surveillance management approach must content with the loss or addition of cameras. The loss could be the result of battery outages or network disruption, while an addition could be the installation of cameras to improve coverage or to provide redundancy. The other environment change is the introduction of obstacles (an m-sided polygon) within the space. An obstacle can be considered a hole, which means the obstacle itself is not to be monitored. For this paper the obstacle must also be covered along with the walls of the space. As with the addition and removal of cameras, a camera management approach must contend with the introduction and removal of obstacles over time.

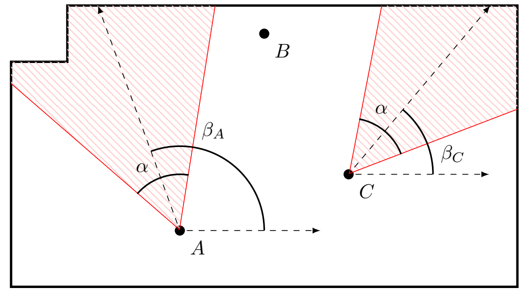

Fig. 1. Example 6-sided polygon floor space with three cameras (labeled A, B, and C). Each camera has the same view angle α and an individual orientation (swivel) angle β_i. In this example cameras A and C are activated (turned-on), while camera B is not activated (turned-off).

III. An Evolutionary Approach to Surveillance Management

Identifying good surveillance configurations (camera activations and orientations) can be considered a search problem that attempts to locate configurations that maximize coverage with the smallest number of cameras. Given the size and complexity of the search space, search heuristics, such as Evolutionary Algorithms (EAs), are often used for this type of problem. In addition, EAs have the benefit of constantly searching for solutions. This search characteristic is helpful for problems where the search space may dynamically change [6].

EAs naively mimic evolution to find better (more fit) surveillance configurations by discovering, recombining, and altering portions of current configurations to generate new ones. This is achieved by maintaining a set of solutions (referred to as a pool) rather than a single solution. Before an EA can be applied surveillance management, a genetic representation of the problem domain, methods of determining feasibility, an understanding of configuration fitness, and the design of EA operators must be carefully addressed.

A. Camera Configurations and Fitness

EAs represent potential solutions as a chromosome consisting of multiple traits, or parts of the solution. As described in Section II, each camera has two settings $(a_i, \beta i)$. The first setting is a binary value indicating if the camera is active or inactive (or or off) and the second is the orientation angle. A surveillance configuration s is then a list of camera settings, one per camera. Using the chromosome representation, the settings for a specific camera are a trait or gene, while the surveillance configuration is a chromosome.

A measure of fitness is also important for evolutionary algorithms to ensure fitter chromosomes are more likely to survive and influence the next generation. For surveillance management, the fitness of a chromosome (surveillance configuration) is multi-objective since the approach seeks the maximum coverage using the fewest cameras [8]. Several