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Advances in Applied Spatial Optimization: Modeling and Optimising Wildfire Detection

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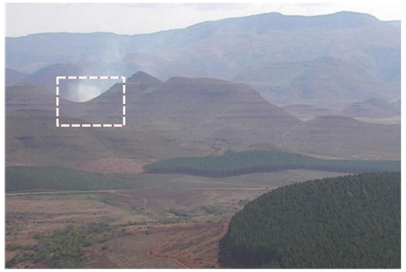
Introduction

Camera-based wildfire detection systems (CWDSs) comprise a number of specialised tower-mounted cameras that monitor the surrounding environment with the aim of providing ***early wildfire detection***. When configuring a CWDS layout, the number of candidate sites at which to place the towers may far outnumber the camera towers available for placement. It is therefore necessary to carefully select a smaller number of final sites from the larger set of candidates [1].

A system-site selection framework that alleviates this burden has been developed in collaboration with the South African *ForestWatch* CWDS, with operations in South Africa, Australia, Spain, Canada and the USA. The principal site requirements of this framework are (a) to ***minimise the need for user input*** to select candidate sites, (b) to identify sites that are superior candidates for ***system-site optimisation***, as opposed to single-site optimization, and (c) to facilitate the monitoring of ***large territories*** and therefore the ability to consider a large number of candidate sites [2].

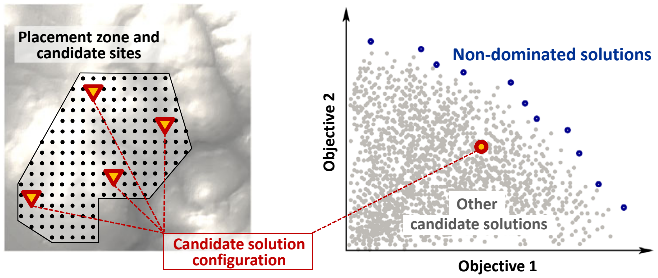



A typical camera used in ForestWatch CWDSs, and a fire detected by the system

Candidate solutions and evaluation

Towers are placed at ***candidate sites*** that are contained in a feasible ***placement zone*** (PZ) on the terrain surface (see figure below) and a ***candidate solution*** is a specific configuration of towers at a selection of these sites [1,2].

A candidate solution's quality is measured by the visibility cover it achieves with respect to different areas of interest (called ***Cover Zones***). In the CWDS optimization problem, ***two visibility covering objectives*** are considered (as in the right of the figure). When analysing the quality of all the possible candidate solution configurations with respect to the objective functions, ***decision makers*** desire the set of ***non-dominated solutions*** – also called the ***Pareto front.***

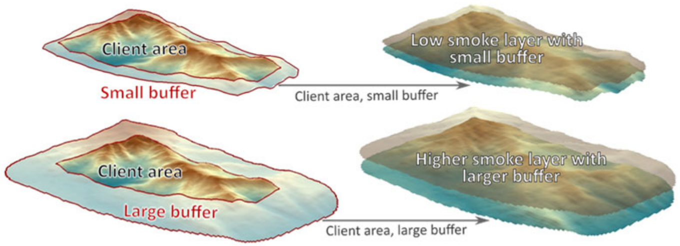


Solution approach

Smoke layers (Cover Zones)

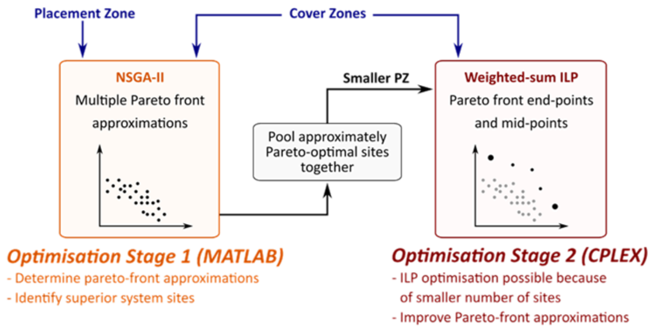
The lower above the terrain surface a smoke plume may be detected, the sooner suppressing action may be taken after the onset of a fire. Terrain and vegetation are, however, more likely to obstruct a camera's visibility of smoke when it is near the terrain surface or when the fire is in a valley or behind a hill. The overall detection potential of a CWDS therefore also depends on its ability to detect smoke at higher levels above the terrain surface (after clearing obstructions) [1,2]. Furthermore, CWDSs are configured in such a manner that they achieve satisfactory visibility cover over ***buffer zones*** added to the smoke layers, for the purpose of detecting fires outside the area at risk (typically ***forestry client properties***) and which may rapidly spread onto client property.

A **low smoke layer** is used for ***near-immediate detection and rapid client response***, and has a smaller buffer zone for detecting fires near the client boundaries which pose an immediate threat of crossing over into client territory (see figure below). A ***higher smoke layer*** serves the purpose of detecting smoke not detected at the lower layer due to visibility obstructions, and which has ***risen further to be (potentially) visible***. The higher smoke layer is associated with an extended buffer zone which allows for the monitoring of fires further outside the client area – these fires need to be monitored, but do not necessarily require immediate response [1,2].



Optimization

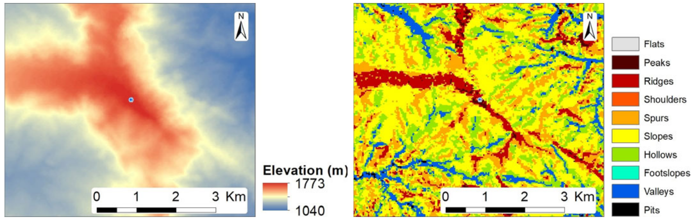
A large number of candidate sites (a result of the vast expanses of terrain to consider for placement) leads to ***significant complexity*** in the search for optimal sites. A ***two-stage optimization process*** is therefore followed (see figure below). In the first stage, the NSGA-II algorithm [3] is employed to determine multiple Pareto front approximations and the constituent sites from these layouts are pooled together. The result is a new PZ which is sufficiently small to be provided as input into traditional optimization software (e.g. CPLEX), resulting in an improved Pareto front [2].



Focussing the search

Reducing the size of the set of feasible candidate sites in the PZ reduces the complexity of the search for the final tower site locations. At the same time, the search efficiency and ***solution quality may be improved*** if the PZ is ***limited to sites that are superior candidates*** in terms of their potential contribution to overall system detection performance [2].

Ridges and peaks are consistently considered to offer superior observer visibility compared to sites classified otherwise, and the implementation of *geomorphon* landform classifications [4] has been investigated [2]. In one study, limiting the PZ to sites classified as peaks and ridges resulted in an 80% reduction in the number of candidate sites, resulting in improved solution quality along with a conspicuous reduction in the computation times of the optimization approaches [2].



Terrain elevation around a proposed site location (left) and corresponding geomorphon landform classification of the surrounding terrain (right).

Real-world application

The framework has matured into a ***fully-functioning and applied optimization tool***. This was showcased by its recent, ***real-world application*** for the selection of sites for a four-camera CWDS in South Africa's Southern Cape. In 2017, in the town of Knysna (a mere 60 km away), one of South Africa's most devastating fires ever occurred. The study area exhibited similar vegetation and terrain as the Knysna area – a similar catastrophe occurring is thus a very real possibility and was one of the driving factors for the decision to install a CWDS. ***Rapidly-determined*** layouts from the framework ***drastically outperformed*** the coverage achieved by sites initially proposed after weeks of planning by ***technical experts*** with years of experience in forestry and, in particular, tower site selection.

The framework and its application has been selected as a finalist for the International Federation of Operations Research Societies' triennial award for Operations Research in Development 2020.

References

[1] Heyns, A.M., du Plessis, W.P., Kosch, M., & Hough, G. (2019). Optimisation of tower site locations for camera-based wildfire detection systems, *International Journal of Wildland Fire*, 28(9), 651–665.

[2] Heyns, A.M., du Plessis, W.P., Curtin, K.M., Kosch, M., & Hough, G. (2020). Analysis and exploitation of landforms for improved optimisation of camera-based wildfire detection systems, *International Journal of Geo-Information*, Under revised review.

[3] Deb, K., Pratap, A., Agarwal, S., & Meyarivan, T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II, *IEEE Transactions on Evolutionary Computation*, 6, 182–197.

[4] Jasiewicz, J., & Stepinski, T.F. (2013). Geomorphons – a pattern recognition approach to classification and mapping of landforms, *Geomorphology*, 182, 147–156.