Developing Spatial Optimisation Techniques for Viewpoint Location Problem

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Abstract

This paper suggests four spatial algorithms explored robust viewpoint location techniques: an extensive iterative search technique; a conventional solution based on the Tornqvist algorithm; genetic algorithm; and simulated annealing technique. The solution performance of these algorithms is compared on a set of viewpoint site problems and the experiment results demonstrate the useful feasibility. Finally, this paper presents the potential applicability of new spatial search techniques for GIS visibility analysis.

Key words: Visibility analysis, Viewpoint site problem, Spatial optimisation algorithms, GIS

1. Introduction

Current Geographic Information System (GIS), for dealing viewpoint location problem, provides not only what areas of a surface can be seen by one or more viewpoints, but also, for any visible position, how many viewpoints can see the position. The result can be displayed to detect visible and non-visible areas with their visibility attributes (Burrough and McDonnell, 1998). However, the design of an optimum set of visibility sites that search for the maximum area covered with the minimum number of viewpoint or observer sites, is a combinatorial problem for which no analytical solutions are proposed and no tools exist within current GIS (Lee, 1991; Kim et.al., 2004; Kim, 2005). The issue of this search problem is how to measure the optimality of the viewpoint location problem when a heuristic generate its optimal location solution. The nature of optimal solution in optimisation problems implies that there are well-defined or robust solution heuristics, which are more likely to produce better visibility solution rather than existing points generated by a heuristic.

2. Problem representation

Since the viewpoint site selection aims to locate a set of points that maximise visibility, the model formulation can be represented as followed.

\[
\begin{align*}
\text{Maximise Visibility, } F(V) &= \sum_{i=1}^{n} \sum_{j=1}^{m} V_{ij}\Phi_{ij} \\
\text{Subject to} & \\
0 & \leq \sum_{j=1}^{m} V_{ij} \leq n \text{ for } j = 1, 2, 3, \ldots, m \\
0 & \leq \sum_{i=1}^{n} V_{ij} \leq m \text{ for } i = 1, 2, 3, \ldots, n \\
0 & \leq \sum_{i=1}^{n} \sum_{j=1}^{m} V_{ij} \leq (n \times m)
\end{align*}
\]

Where the visibility objective function represents \( F(V_{1,1}; V_{2,2}; V_{3,3}; \ldots; V_{n,m}) \) in which \( V_{ij} \) is the visibility Boolean of of \( i^{th} \) viewpoint location on \( j^{th} \) grid surface. The \( V_{ij} \) is true and counts 1 if \( i \) viewpoint can see the \( j \) surface cell, or false and counts 0 if not. \( \Phi_{ij} \) is to check overlapping visibility area of \( i^{th} \) viewpoint such that if the surface cell is visible by previous site, the visibility count is not added even though it can be visible from the viewpoint. Thus, the cumulative intervisibility result is evaluated to meet the viewshed objective. \( n \) is the number of viewpoints placed on the surface, \( m \) is the total number of cells of the surface.

3. Optimisation heuristics for viewpoint location problem

3.1. Eight equi-spaced point method

The eight equi-spaced technique was originally built to determine new search neighbours within a SA algorithm used to solve a waste disposal site selection problem (Muttiah, et al., 1996). For the visibility problem, the search procedures can be used directly to find good starting viewpoint
locations on a DEM where each viewpoint has its own location information (e.g. coordinates) and elevation value. Using this data, the visibility quality (total viewsheds) of eight equi-spaced points in a circular neighbourhood is found. This neighbourhood search process is continued until no visibility improvement is displayed. The following pseudo-code describes the visibility search procedures of the eight equi-spaced search technique.

3.2. Tornqvist algorithm

In the late 1950s and early 1960s, Tornqvist, a Swedish geographer, developed a location optimisation algorithm for solving facility location problems (Tornqvist et al., 1971). To be a robust location heuristic for the visibility problem, the algorithm employed a unique explorative search technique that examines its solution one step at a time along a west and east direction and a south and north direction until no further reduction in the objective function can be obtained. The following pseudo-code describes the iteration search steps of the Tornqvist algorithm derived for the visibility problem.

3.3. Genetic algorithm

A genetic algorithm (GA) is a search algorithm that applies evolutionary rules and biological operators to solve complex optimisation problems (Goldberg, 1989). For solving the visibility problem, a potential solution to the problem is represented as a ‘binary gene’ – a fixed number of binary bits. Then the GA randomly selects an initial population representing binary bits to generate starting solution that converts numeric coordinates of visibility site pixels to a set of binary bits. The fitness of the current visibility solution (i.e. total visible cells) is then evaluated to determine whether this solution can be used for a new population by the selection rules in the GA process. In next, a new population sets are created from the selected old generation by applying the genetic operators. This evolutionary process is continued until a termination condition is met for which a fixed generation number is used in this paper. The following pseudo-codes present the visibility GA that reflects all evolution processes.

3.4. Simulated annealing algorithm

Why SA algorithm is suitable for the visibility problem is that at first, maximum visibility sites generates multiple suboptima, which means that there may exist several different viewpoint locations representing same visibility on a DEM. Secondly, traditional hill climbing or random search methods (e.g. Monte Carlo optimisation search types) can get stuck in local suboptima since a move is only made when a better solution is found whilst simulated annealing technique can overcome the local optimum with robust probabilistic selection method, called the metropolis criterion (Kirkpatrick, et. al., 1983). For the visibility annealing process, the visibility SA employs a binary search concept that reduces temperature rate by fraction of acceptance moves and acceptance rate of the Metropolis criterion at each search step.

4. Experiment results and analysis

For the first procedure, the viewpoints are placed at random over a DEM grid surface and each run of the four algorithms constitutes several attempts at the placement of viewpoints. For this purpose, the four algorithms were run for 100 times with different starting viewpoint coordinates randomly generated in the iteration. Figure 2 shows the solution values of the four algorithms, which elucidates the outperforming features of the new algorithms (GA and SA) in terms of solution quality (efficiency) and solution consistency.
For the solution stability, Figure 3 shows the algorithmic consistency for the various viewpoint problem cases of the four methods. For the second strategy that implements same starting configuration, figures 4 and 5 present the comparison of the best solution values and the standard deviation values, respectively. For all given viewpoint sites, the GA almost outperforms the other three algorithms in terms of the visibility solution.
The algorithmic consistency is clearly identified in Figure 5 that shows the various solution set comparisons for the four algorithms. As with the results shown in the previous section, for all given visibility sites, the GA and the SA algorithms produce the most consistent solution performance relationship over the 8 equi-circle and Tornqvist algorithms.

Figure 4. Comparison of the solution consistency on the same initial restarting configuration
With regard to computational performance, the four algorithms produce different aspects compared to the visibility solution. It has been found that the two conventional algorithms always take less CPU time than than the GA and SA algorithms. In general, for the visibility site problems, the 8 equi-circle technique run 10 times faster than the Tornqvist algorithm, 20 times faster than the GA and 40 times faster than the SA algorithm. Users may accept the inferior visibility solution of the eight equi-circle technique because of its faster computing time whilst some users prefer the best visibility solution which can guarantee the best visibility. Given extra computing times, the user should take into account additional work spending times to explore the suitable parameters for the problems. In general, the conventional algorithms require more extra works than the GA and SA because the GA and SA are more flexible to set up parameters than the conventional algorithms. Therefore, for the computational performance, there exists a trade-off problem which the users should decide.

5. Conclusion

In conclusion, as the algorithms have been applied to solve the visibility optimisation problem, the application scopes of the visibility algorithms can be extended into various visibility analysis fields and the solution performances of the intelligent algorithms can be also compared with the conventional algorithms. Under the reasonable speedy computing environments it has been found that the GA presents the best solutions and the SA algorithm presents the most robust algorithmic consistency for various restarting solution conditions. However, several limitations and research issues are also left for further work. At first, this paper has used the visibility data based a DEM grid data. As the DEM data represents only a regular grid surface, the algorithms need to be tested with other irregular TIN topology data because the irregular TIN data set can provide another realistic visibility problem space for the algorithms. Thus, when the intelligent algorithms are applied to the TIN data, the applicability and feasibility can be extended for more suitable robust visibility algorithms for GIS. Secondly, the algorithmic precision of this paper is naturally dependent on the DEM resolution. Therefore, if a higher spatial resolution DEM is provided with different spatial interpolation techniques, the four algorithms can provide more improved precision of visibility quality and applicable usefulness for real practices. Lastly, the outstanding performance of the intelligent algorithms has not been linked to a GIS environment so that they did not clearly demonstrate the usability of GIS as a useful GIS spatial optimisation approach.

References:


