Solution Approaches to Multiple Viewpoint Problems: Comparative Analysis using Topographic Features

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다중가시점 문제해결을 위한 접근방법: 지형요소를 이용한 비교 분석을 중심으로

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ABSTRACT

This paper presents solution heuristics to solving optimal multiple-viewpoint location problems that are based on topographic features. The visibility problem is to maximise the viewshed area for a set of viewpoints on digital elevation models (DEM). For this analysis, five areas are selected, and fundamental topographic features (peak, pass, and pit) are extracted from the DEMs of the study areas. To solve the visibility problem, at first, solution approaches based on the characteristics of the topographic features are explored, and then, a benchmark test is undertaken that solution performances of the solution methods, such as computing times, and visible area sizes, are compared with the performances of traditional spatial heuristics. The feasibility of the solution methods, then, are discussed with the benchmark test results. From the analysis, this paper can conclude that fundamental topographic features based solution methods suggest a new sight of visibility analysis approach which did not discuss in traditional algorithmic approaches. Finally, further research avenues are suggested such as exploring more sophisticated selection process of topographic features related to visibility analysis, exploiting systematic methods to extract topographic features, and robust spatial analytical techniques and optimization techniques that enable to use the topographic features effectively.

KEYWORDS : Visibility Analysis, Multiple Viewpoint Problem, Topographic Features, Visibility Search Techniques

요 약

본 논문은 가시권역의 최대화를 만족하는 가시권 분석에 있어 지형요소가 어떻게 이용될 수 있으며 이러한 최적 다중 가시점 탐색 문제에 있어 지형요소의 이용이 얼마나 효과적인지를 살펴보는

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연구이다. 이를 위하여 다양한 지형상태를 반영하는 지역의 DEM 자료와 각 DEM자료에 대한 지형요소 (peak, pass, pit)의 특징을 반영한 여섯 종류의 탐색방법을 제시하고 전통적인 공간 휴리스틱 (spatial heuristic)과의 비교 분석 (계산 시간과 총 가시권역 크기)을 통해서 지형요소를 이용한 방법의 효율성과 적용 가능성을 살펴보았다. 연구결과로써, 가시구역의 중복을 최소화하기 위해 제시된 버퍼링을 이용한 방법의 경우, 비록 공간 휴리스틱 방법에 비해 적은 가시구역 면적을 제시하였지만, 컴퓨팅 시간적인 측면에서 많은 이점을 제공하고 있음을 볼 수 있다. 또한 연구지역의 DEM상의 각각의 개별 그리드 셀을 대상으로 전체 DEM에 대해 계산된 가시구역을 이용한 방법의 경우, 비록 부가적인 계산 시간이 소요됨에도 불구하고 단순한 지형요소를 이용한 방법보다 향상된 분석 결과를 제시하였음을 알 수 있다.

주요어 : 가시권 분석, 다중가시점문제, 지형요소, 가시권 탐색기법

INTRODUCTION

Visibility problem is to maximise the viewshed area for a set of viewpoints on DEM. A series of locations that collectively maximise the visible area must be selected. A wide range of geographic information system (GIS) operations routinely use this type of operation, which also has broad application in facility planning, such as locating telecommunication relay towers (De Floriani et al., 1994), locating wind turbines (Kidner et al., 1999), evaluating optimal path routes (Lee and Stucky, 1998), exploring radiowave propagation modelling (Wagen and Rizk, 2003), examining natural surveillance modelling (Desyllas et al., 2003), and analysing archaeological locations (Lake et al., 1998; Lake and Woodman, 2003).

Viewshed calculations are potentially time consuming, not least because of the large number of pixels which need to be considered when using a gridded DEM as the terrain model. Therefore a good deal of work has been done to develop efficient viewshed algorithms (Sorensen and Lanter, 1993; Wang et al., 1996; Fisher, 1991, 1993, 1996). Wang et al., (1996) developed a new fast viewshed calculation algorithm for DEM using neighbourhood grid cells. Recent developments have made use of visibility graph theory (O'Sullivan and Turner, 2001), statistical sampling (Franklin, 2000), reverse viewshed analysis (Kidner et al., 1999; Rallings, et al., 1999) and least-cost computation methods for determining optimal paths (Lee and Stucky, 1998).

However, few studies have explored solution approaches, especially approaches based on topographic features (Kim et al., 2004). This study examined how the solution process affects the solution of the visibility problem. Ideally, it may be possible to identify good optimal viewpoint candidates before running a full spatial search. These candidates, rather than random points, can then be used for the initial configuration. The use of good candidates is vital for the solution process, as good candidates not only reduce computation time but also produce the optimal solution for the viewpoint location problem. In this paper, four approaches to solving the visibility problem are proposed that are based on fundamental topographic features of DEM. This paper also investigates whether consistent optimal viewpoint location patterns exist on different DEMs; whether the tendency of optimal viewpoints to be located on high mountain peaks and ridges is also apparent in flatter terrain applications; and whether the characteristics of viewsheds of peaks and ridges also pertain for other terrain surface types.

In many applications, such as the location of mobile telephone masts, it is necessary to identify a series of viewpoints which can collectively 'see' as much of an area as possible. There are two major difficulties in solving this problem

- It is surprisingly difficult to predict which individual points on the landscape are going to have the highest visibility and would therefore make good candidate viewpoints. Although visible points tend to be high, not all high points have good visibility.
- The multiple viewpoint problem is combinatorial. To identify the best 5 locations it is computationally infeasible to try all possible combinations of 5 points to identify the best. Therefore some sort of heuristic approach is needed.

The objectives of this paper are at first investigate the visibility problem of multiple viewpoint problems for which topographic features (peaks, passes, and pits) are extracted. Second, six solution methods based on the topographic features and distance buffering, and spatial heuristic are explored in order to investigate solution effectiveness of the topographic based methods in the viewpoint problem. Finally, this paper aims to identify the effectiveness of the topographic features based methods by using solution quality (maximized visible areas) and computing time.

In order to obtain the research objectives, next section discusses solution approaches of the viewpoint location problems and details of solution methods and processes. In turn, it describes the characteristics of topographic features to visibility analysis. The experimental results are followed and finally this paper concludes with the identification of the usefulness of the topographic features to the viewpoint problems by which optimal multiple viewpoint location problems in GIS would be solved efficiently without relying upon computational heuristics.

SOLUTION APPROACHES AND METHODS

The first solution approach selects the n pixels with the highest peaks or the largest absolute viewshed sizes. Generally, this is a simple, easy approach; the most difficult part is identifying the landscape points that have the greatest visibility without calculating the visibility index for all pixels. Intuitively, one might expect the highest points to have the largest viewshed. A number of studies have identified peak features as a key factor in viewshed optimisation, as peaks tend to have higher average visibility than other landscape elements (e.g., Franklin and Ray, 1994; Lee, 1994; Rana 2003).

The second solution approach selects the point with the largest viewshed and then chooses the next highest point within a certain distance (e.g., 1 Km) of the first point. This process is repeated until n points are obtained. Although high visibility locations tend to fall on ridges and peaks (Lee, 1994), the pattern is not necessarily simple. Some ridge points can be obscured by other ridges of higher elevation, and higher neighbouring peaks may have similar high or low values. This situation suggests that to reduce viewshed overlap, higher elevation point candidates that are some distance away from the initial highest point should be selected to minimise viewshed overlap at every point.

The third solution picks the point with the largest viewshed, and then picks a peak with a) the next largest viewshed and b) the smallest overlap with the first point's viewshed. This method differs only slightly from the second method, but it has a more robust search approach. While the highest points do not always produce a larger viewshed than lower points, all points with high visibility tend to be located on peaks and ridges. Thus, for a high peak that produces a large viewshed, this solution can be expected to outperform the optimal viewpoint location solutions obtained from the previous two approaches. Additionally, since only a small number of pixels have very high visibility values (as noted by Franklin and Ray, 1994), a large number of multiple viewpoint location solutions may feature the same pixels. This assumption can be tested by examining the visibility values of chosen locations. The fact that pixels with the largest viewshed values work so well (almost as well as peaks) suggests that high visibility pixels, rather than combinations of lower visibility pixels with non-overlapping viewsheds, may work well for multiple-viewpoint problems where the aim is to maximise the total visible area. However, the weakness of this method is that it requires prior viewshed computation for all pixels, which requires a potentially time-consuming process for large DEMs.

A final approach is evaluated through comparative benchmark tests. A robust spatial optimisation heuristic is applied and the results are compared with the results obtained using the previous three approaches. This paper examines a visibility problem analogous in form to facility location-allocation models that search for optimal facilities based on maximised accessibility. Thus, Teitz and Bart's swap heuristic (Teitz and Bart, 1968) can be used with the substitution process set to search for optimal viewpoint pixels. For the visibility optimisation, an initial solution is generated by randomly selecting the first p candidates from the list of topographic features used in the first three approaches. The swap heuristic is then used to find optimal locations. For example, a list of the 100 highest and largest-viewshed pixels is generated. This list could then be used as a random starting solution set for the substitution process. This method produces a close-to-optimum solution. However, the time-demands and complexity of the model must also be considered.

In Kim et al (2004), the idea of applying location-allocation heuristics to multiple viewshed problem was introduced. This is based on an analogy between the two problems - in the multiple viewpoint problem customers (points on the landscape) are allocated to services (viewpoints) in such a way that the number of viewpoints is minimised and the allocation of customers is maximised. A number of location-allocation heuristics were compared and found to give good solutions for between 2 and 10 viewpoints in reasonable amounts of time.

In this work, we compare one of the location-allocation heuristics, with a series of more direct attempts to solve the problem. Assume we wish to place n viewpoints in an area in order to maximise the visibility coverage. The heuristics compared are:-

Method 1. Take the n highest peaks. This will be very rapid, but is not likely to produce a good result. However, it serves as a means of comparison with the other methods which are likely to be slower but produce better results.

Method 2. Take the highest peak as the first point. For subsequent points, take the highest peak which falls outside a certain distance (e.g. 1 Km) of the existing points in the set - this avoids picking clusters of points with similar viewsheds.

The first two methods will be rapid, because there is no calculation of visibility in the selection of the points. The other two methods begin with a calculation of the visibility of every point in the DTM and are then similar to methods 1 and 2 but using visibility rather than elevation to select the best points.

Method 3. Take the n most visible points.

Method 4. Take the most visible point as the first point. For subsequent points, take the most visible point which falls outside a certain distance (1 Km) of the existing points in the set - this avoids picking clusters of points with similar viewsheds.

In next, a robust spatial optimisation heuristic is applied and the results are compared with the results obtained from the above four approaches. For the heuristic, Teitz and Bart's swap algorithm is used with the substitution process set to search for optimal viewpoint pixels. For the visibility problem, a list of 100 highest peaks and largest visible points is generated. This list can then be used as a random starting solution set for the substitution process.

Method 5. Take the n most visible points from the list of the 100 highest peaks.

Method 6. Take then most visible points from the list of the 100 largest visible points

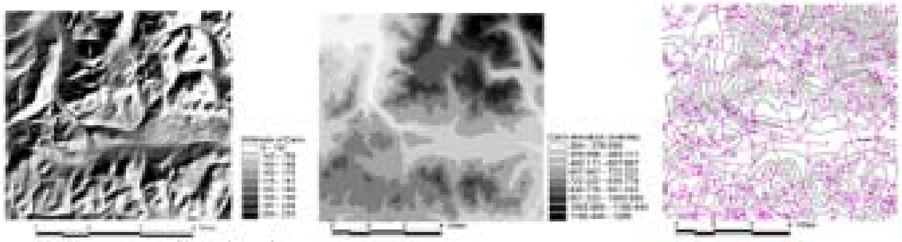
These two methods expect to produce close-to-optimum solution. However, the time demands and complexity of the swap heuristic solution model must also be considered.

TOPOGRAPHIC FEATURES AND VISIBILITY ANALYSIS

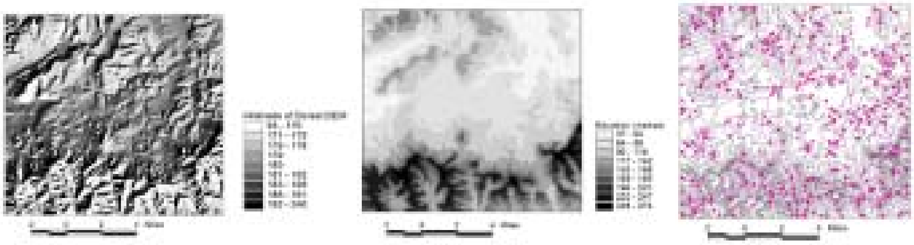
A number of visibility analysis studies have found that some fundamental topographic features (e.g. peaks, pits, passes, ridges, and channels) play important roles in measuring visibility dominance and reducing computation time. Critical topographic features such as peaks and ridges can dominate visibility from ground locations and can also serve as good viewpoint sites (e.g., Lee, 1994; Rana, 2003). Thus, topographic features, including peaks and ridges, can be used to reduce the number of candidate observation points and to effectively search for potential optimal viewpoint locations; furthermore, this approach might also help reduce computation time with little loss of optimal solution quality.

Figure 1 shows five DEM study areas. Each Ordnance Survey PANORAMA DEM tile covers 20 x 20 Km and has a 50 meter resolution. Study areas cover terrain that ranges from high mountains to lowland plains. For instance, the Cairngorm area (Figure 1a) has a minimum elevation of 264 m and a maximum elevation of 1,295 m, whereas Norfolk (Figure 1e) has a minimum elevation of 21 m and a maximum elevation of 95 m. Landserf was used to classify the 50 Meter DEMs and to extract the following fundamental topographic features: peaks, passes, pits, ridges, and valleys.

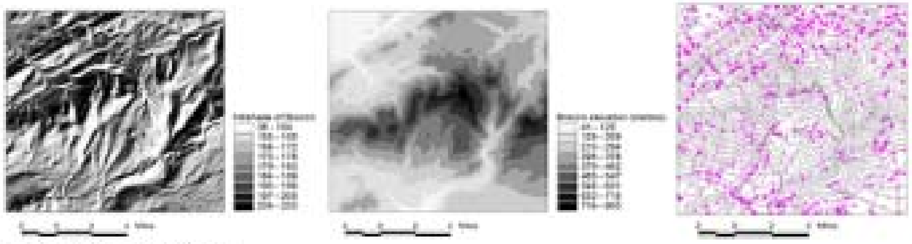
The graphs of visibility against elevation for five areas in the UK (Figure 2) illustrate the relationship previously reported by Lee (1994) and Franklin and Ray (1994) -



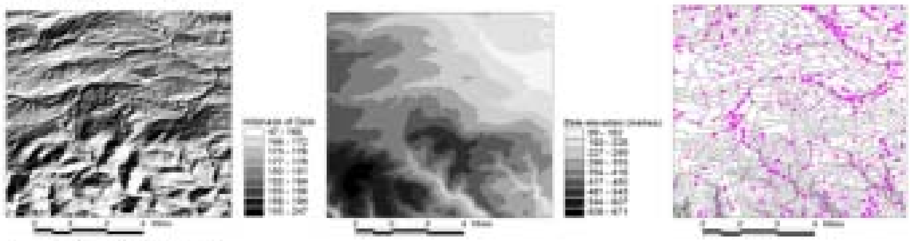
a. Cairngorm, Scotland



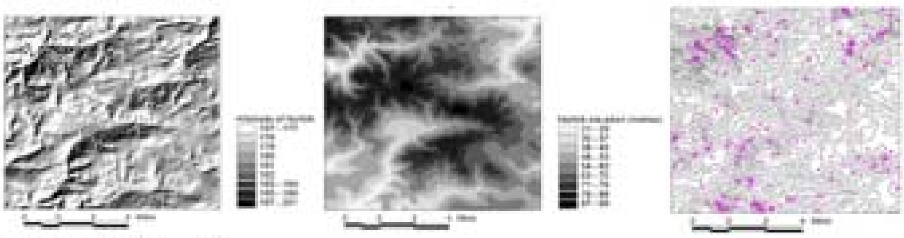
b. Dorset, England



c. Brecon, England



d. Dales, England



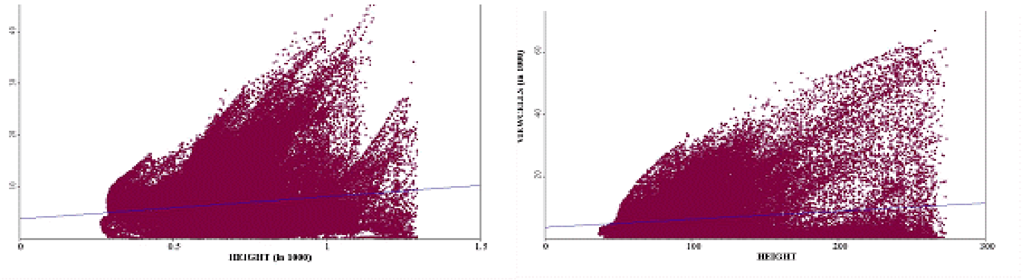
e. Norfolk, England

FIGURE 1. Hill-shade image, elevation map and distribution of topographic features (pits, passes, peaks, ridges and valleys) of study areas

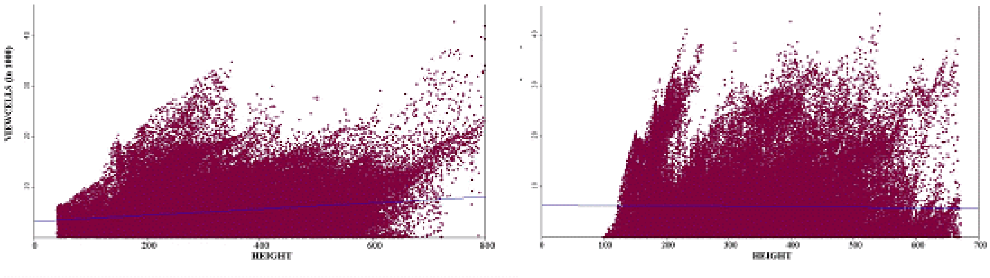
although all the high visibility points have high elevation, many elevated points have low visibility. Figure 2 also shows the low correlation between high visibility and high elevation, which corresponds to the previous research works. The low correlation relation, therefore, motivates extensive research avenues to explore the relationship between visibility and elevation in the maximum visibility problem.

Lee (1994) suggested that topographic position, rather than absolute elevation, might be a better predictor of visibility, with points on ridges and peaks tending to have high visibility values. Jo Wood's LANDSERF program (1998) was used to classify the DTMs, and Figure 3 confirms Lee's findings, showing that

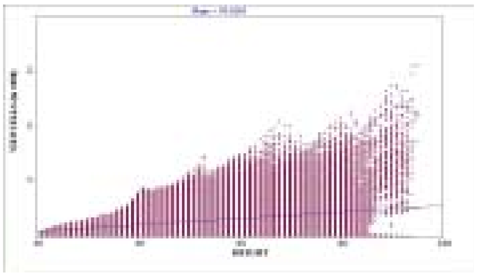
- On average peaks and ridges have higher visibility than other parts of the landscape



a. Cairngorm, Scotland b. Dorset, England

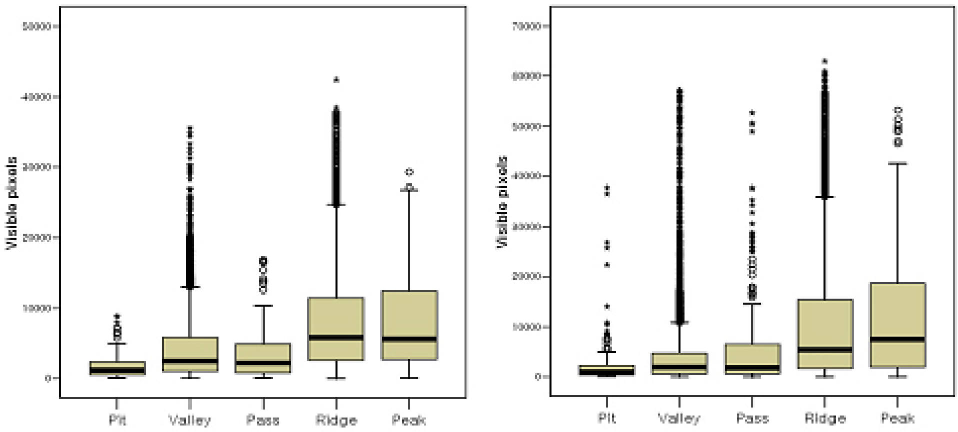


c. Brecon, England d. Dales, England

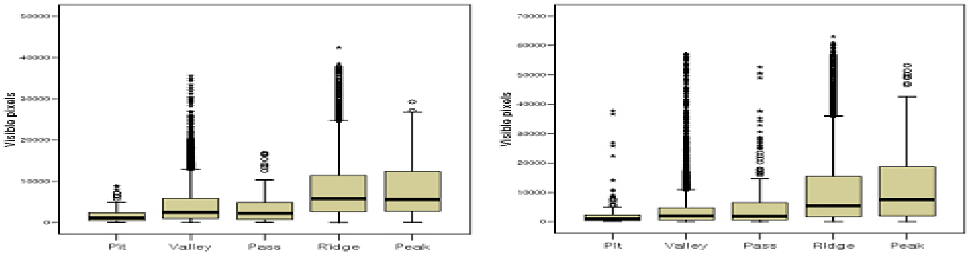


e. Norfolk, England

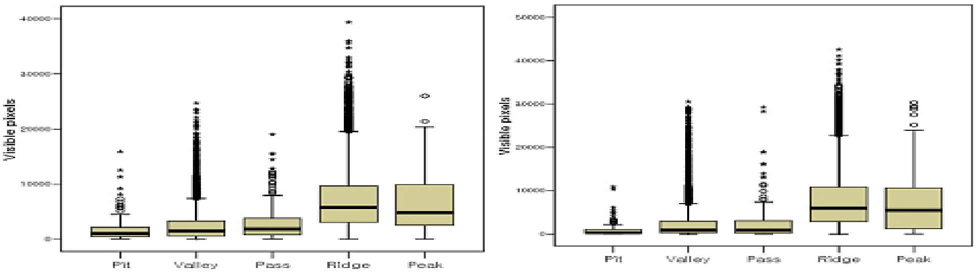
FIGURE 2. Visibility graph against elevation of study areas



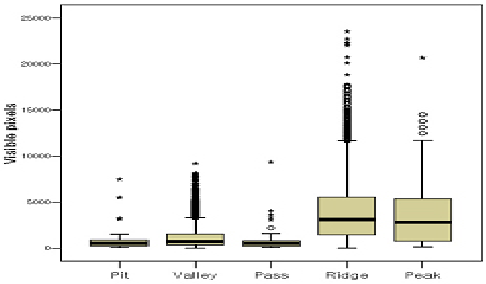
a. Cairngorm, Scotland b. Dorset, England



a. Cairngorm, Scotland b. Dorset, England



c. Brecon, England d. Dales, England



e. Norfolk, England

FIGURE 3. Visibility values of topographic features for the DEMs

- The highest visibility points all lie on peaks or ridges.

In our initial work we have focused on peaks and largest visible points, since this result in a smaller number of candidates.

RESULTS AND DISCUSSION

We tested the above processes on each 20x20 km tile from the Ordnance Survey 50m PANORAMA DEM, for five areas in Great Britain (see, Figure 1). They cover from a quite flat area (Norfolk area) to a high mountain area (Cairngorm area). Each of the five DEMs has 400 pixels in both X and Y, giving a total number of 160000 pixels. This is rather larger for some of the programmes in the visibility analysis so we made use of the Sheffield High Performance Computing Grid. The running times are summarised in Table 1. It is important to note that the prior viewshed computation for all pixels for the methods 3 and 4 analysis is not included. Hence, it should take into account their extra pre-processing computing time to evaluate computational performance.

Figure 4 shows the visibility results of the six methods for the DEMs. From the viewsheds, the inclusion of the distance criterion (e.g. outside of 1km buffer distance) generates better viewsheds than the methods taking only highest peaks or most visible points (Methods 1 or 3). However, an interesting point is that the method taking the largest visible points with the swap algorithm (method 6) produces best visibility coverage than the peak points with the swap algorithm (method 5). This result supports the advantage of the use of visibility rather than elevation to select the best points that maximise the visibility coverage. It also supports the usefulness of distance buffering method which is effective to avoid visibility overlap of peaks located around at highest peaks. Therefore, from the results of Figure 4, it can be inferred that sole use of high peaks is not capable of searching the best viewpoint locations in the multiple viewpoint problem, and that buffering of search distance is effective to avoid visibility overlap which produces good computing performance. Although some results of the topographic features and distance buffering

TABLE 1. Computing time of five solution approaches for a Dorset DEM (5 optimal best viewpoints search case)

Method	CPU*
1. Highest peaks	1 min. 57 sec.
2. Peaks with buffer distance	1 min 40 sec.
3. Largest viewsheds	2 min. 32 sec.**
4. Viewsheds with buffer distance	2 min. 12 sec.**
5. Swap heuristic with highest peaks	16 hrs. 5 sec.
6. Swap heuristic with largest viewshed	15 hrs. 15 min. 23 sec.

* Sun V880 using Ultrasparc III CPU with a clock speed of 900MHz, equivalent to 3 GHz Pentium 4 performance

** Excludes approximately 72 hours computing time taken for a calculation of the visibility of every point in the DEM identifies methodological progress in the viewpoint problem, spatial heuristic approach is more robust technique to generate the best solution. The synergy of largest viewshed is identified that enable the spatial heuristic to produce the best results with reasonable computing cost. Figure 5 shows an example of the optimal viewpoint location case that illustrates the best five viewpoint locations and the maximised visibility coverage for a Dorset DEM generated by the method 6.

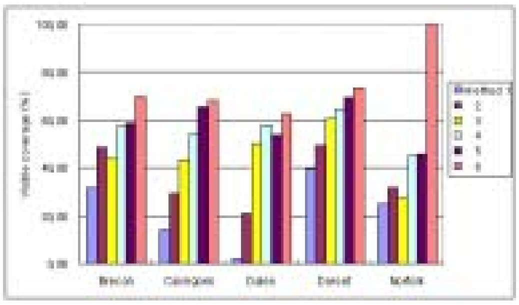
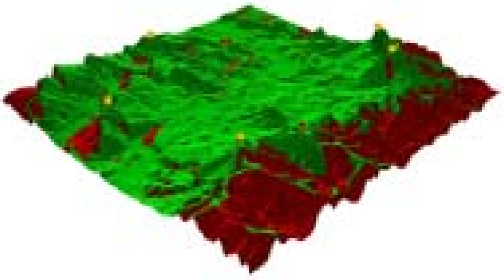


FIGURE 4. Viewshed results of six solution methods for the study areas



* Blue colour indicates 'visible area'; Red colour indicates 'not visible area

FIGURE 5. Five optimal viewpoints and the visibility coverage for a Dorset DEM

CONCLUSION

This paper attempts to explore whether it is possible to identify predictors of potentially optimal viewpoints. This research also presents some results that explores a number of approaches to tackle major difficulties in the multiple viewpoint problems. Points previously identified as repeat viewpoints were analysed (Kim et. al, 2004), as were surface attributes such as the relative elevation of points and slope steepness surrounding a peak (e.g. pointed peaks may have better visibility than flat summits). As the experiment results, it is found that a very simple method (i.e. Methods 2 or 4) produces results which are nearly as good as sophisticated heuristics (i.e. Methods 5 & 6) but in fraction of the computing time. It is also clear that calculating visibility for each pixel improves results. There is therefore a need to develop rapid methods of estimating visibility.

From the results of the above experiments, therefore, it can be inferred that the sole use of high peaks is not capable of searching the best viewpoint locations in the multiple viewpoint problem, and that buffering of search distance is more effective than sole use of peaks and viewshed in order to produce larger viewshed areas with reasonable computing performance. Although some results of the topographic features and distance buffering identifies methodological progress in the viewpoint problem, spatial heuristic approach is still robust technique to generate the best solution. however, it is identified of the synergy of largest viewshed that enables the spatial heuristic to produce the best results with reasonable computing cost.

Further testing could use a random 10% of pixels and compare results with other solutions. This method may achieve decent results if a large enough subsample is used, because a large subsample will likely include some points with fairly high visibility values. Total viewshed calculations based on the random choice of n observers could also be compared with viewscape coverage based on the selection of n optimal observers to see how optimal selection improves the solution. It would also be interesting to rerun these tests and maximise the visible area in lowland areas, where there are broad applications such as maximising mobile phone coverage in populated areas.

There are also numerous other areas for future research. First, genetic algorithm, simulated annealing, tabu search, or other spatial optimisation algorithms could examine the relationship between solutions and topographic features more extensively. As the visibility problem uses an optimisation process to search for an optimal viewpoint location or viewshed maximisation, we highly recommend a benchmark experiment using robust advanced heuristics. Furthermore, high-powered calculations such as high parallel computing (HPC) and parallelised viewshed calculations could also be applied. Finally, the visibility problem could serve as a test of Grid technologies, and in particular could test Grid computations related to GIS spatial analysis (e.g., Wang and Armstrong, 2003). Grid technology allows for geographically dispersed high-performance computation; and this technology could be used to solve large DEM visibility problems requiring prolonged computation times and have capabilities far beyond those of a single PC or workstation.

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