Optimal Sampling Strategies for Line-Of-Sight Calculations in Urban Regions

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Summary: Smartphone applications are driving a growing interest in 3D modelling – in particular the use of LiDAR for modelling city landscapes at high levels of precision and accuracy. In such dynamic environments, where we wish to make decisions based on places of interest that are in the (rapidly changing) field of view, it is critical that we address performance issues in visibility analysis. This paper explores optimisation of a point-to-point line-of-sight algorithm. This paper outlines a variety of line of sight sampling strategies, together with a number of trials that enabled us to optimise sampling in the context of urban visibility analysis.

KEYWORDS: visibility analysis, vista space, LBS, 3D modelling

1. Introduction

People describe and explore space with a heavy emphasis on the visual senses, yet Location Based Services (LBS) under utilise this as a search parameter (May *et al.* 2005), relying instead on proximity in Euclidean or network space. For an urban LBS application to include vista space (Montello 1993), the space which can be seen from a static location with only movements of the observer's head, an urban elevation model which includes topography and surface objects is required. Light Detection and Ranging (LiDAR), provides an economically viable solution, as has been previously demonstrated in urban areas (Palmer and Shan 2002, Rottensteiner and Briese 2002, Bartie and Mackaness 2006).

The computational efficiency of Isovist (Tandy 1967, Benedikt 1979, Turner *et al.* 2001) and viewshed (Tandy 1967, Lynch 1976) models has received much attention (De Floriani *et al.* 2000, Rana and Morley 2002, Rana 2003, Ying *et al.* 2006). However in some cases it is not necessary to compute the region visibility (i.e. viewshed), but instead to determine the visibility of a single point, or limited set of points. For example to allow an LBS application to alert you when a friend is somewhere in view, or to determine if the upcoming junction is visible (or not) for inclusion in way-finding instructions (Bartie and Kumler 2010). In other applications, such as for security surveillance, the analysis may be limited to a set of points along a linear feature, such as a boundary fence. In addition object visibility (eg a building) may be estimated by calculating the visibility to a limited set of very important points which define its structure, such as roof ridge lines and outer walls (rather than a large cloud of points).

This research explores performance improvements which can be made to a point-to-point line-of-sight algorithm through the re-ordering of the sampling. The paper takes the form of a short introduction to line of sight (LOS) calculations, LOS sampling strategies, and then presents a number of trials using different sampling approaches.

2. Line of Sight Calculation

The basic line-of-sight algorithm (Fisher (1993), compares the vertical angle created from an observer to a specified target at another location, against the vertical angles from the observer to all cells in between. If any intermediate cell creates a viewing angle greater than that of the observer to target angle, then the target is considered to be not visible (Figure 1). The assumption here is that the target is considered to be visible until proven otherwise, and that the angle from observer to target is the first calculation to which all other angles are compared. As soon as an intermediate cell angle is calculated above that of the target, then the search may be aborted as it has been proven the target is out of sight.

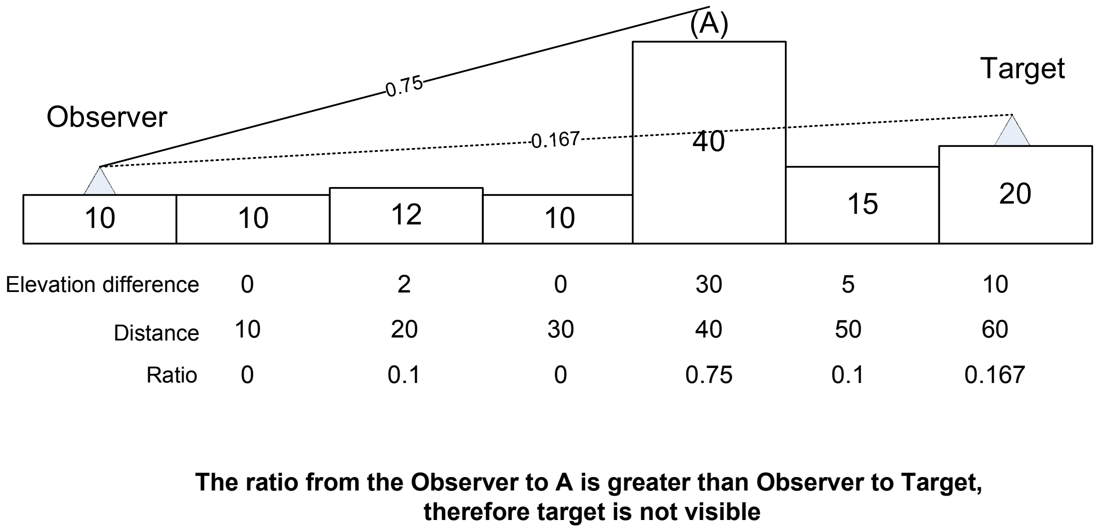

Figure 1: A Line of Sight Approach

If every terrain cell in a line-of-sight path is considered between an observer and target it is referred to as the ‘golden case’ (Rana and Morley 2002), but for a Boolean point-to-point visibility result these intermediate values are not required. The scan order can therefore be modified to test any intermediate cell, and determine if the target is blocked from view. If it is not blocked then another intermediate cell should be tested, repeating this until either all cells along the line-of-sight have been checked and the target is considered visible, or if at some point the target is below the current viewing angle it is deemed to be out of sight and the checking can be terminated. The question is: can the algorithm be made more efficient by considering different sampling steps and different orderings?

3. Line of Sight Sampling

There are a number of ways that the raster Digital Surface Model (DSM) cells between an observer and target can be sampled. These include using a vector ray which is sampled at given intervals along its length (Figure 2a), and a raster approach using the Bresenham's line algorithm, which selects the cells in order along a path from an observer to a designated target (Figure 2b).

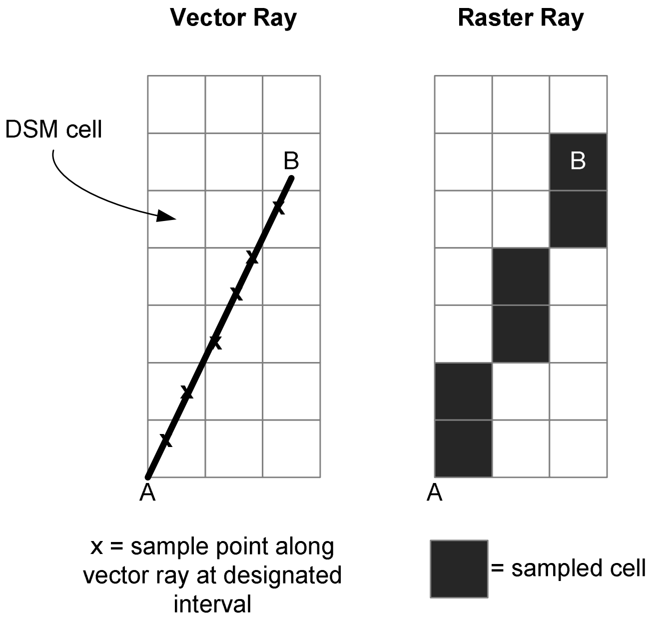

Figure 2: Cell Sampling Approaches based on Vector(2a) and Raster Lines (2b)

Modifications to the sampling order should enable performance improvements in scenarios where the early set of samples can rule out the visibility of the target. The vector approach was found to be more computationally efficient at this task, and allowed for easier search order modifications. The orders implemented were (a-f):

a) Straight Ordering – eg 1234567
b) First, Last Ordering – eg 1726354
c) Divide and Conquer A – eg 1742635
d) Divide and Conquer B – eg 4267531
e) Reverse Ordering – eg 7654321
f) Hop of Length N – eg (when N=2) 1357246

A number of trials were conducted whereby the processor execution time was measured, removing variations resulting from other OS background processes. The experiments were conducted on a DSM of 1 metre resolution for the city of Edinburgh, Scotland

4. Trial 1 – Single Point to Point

A pair of points 1200 metres apart was defined for a case where it was known that the observer could view the target. To increase the workload the same visibility test was carried out 5000 times in succession.

As expected the results (

Table ***1***) indicate no performance benefit in the alternative approaches, as all intermediate cells have to be sampled when the target is visibile. The re-ordering computational overhead impacts methods C,D while other methods exhibited similar calculation times to the original order (A). This table therefore gives an indication of algorithm efficiency for the golden case.

Table 1: Visibility Trial for True Case

Order	A	B	C	D	E	F (N = 5m)
Time (sec)	6.67	6.52	8.60	9.10	6.71	6.41
% of A	100	98	129	136	99	96

Another trial was conducted where the target was out-of-sight. This time the benefits of changing the sampling order were obvious (Table 2), with alternative orders resulting in reduced calculation times.

Table 2: Visibility Trial for False Case

Order	A	B	C	D	E	F (N=5m)
Time (sec)	1.83	0.34	0.74	0.52	0.71	0.62
% of A	100	19	40	28	39	34

To ensure the benefits noted in this single trial held across multiple test location pairs, further trials were conducted.

5. Trial 2 – Multiple Observer-Target Pairs

For the second set of trials 1000 locations were selected randomly across the East side of Edinburgh, with the restriction that they must be in pedestrian accessible locations (i.e. on streets, open spaces, and not on roof tops).

The trial involved testing the visibility from each point to all others, resulting in 1 million visibility tests. The trial was conducted in two ways, firstly with the sample orders being calculated live, and secondly with access to pre-calculated sample orders available from a memory cache. This second approach negates the computation time of calculating the sampling order, but does introduce a minimal cache search and access time. The cache stores the search order for every distance in increments of 1 metre, up to a maximum of 5000m. A check was carried out after each trial to ensure the same results were determined in each case. The calculations were not reversible as an elevation offset of 1.8 metres was applied to the observer, and 0.5 metres to the target. The results from these trials are shown in Table 3.

Table 3: Trial 2 Results - Live and Pre-cached Sort Orders

Order	**A**	**B**	**C**	**D**	**E**	**F** (N=5m)
Live (seconds)	160.03	201.83	416.21	312.50	141.7	38.06
% of A	100	126	260	195	88	24
Cached (seconds)	163.1	196.12	170.28	174.10	136.83	39.13
% of A	100	120	104	107	84	24

This more exhaustive trial showed the additional computation of reordering outweighed any reduced sampling benefits in the majority of cases. Although pre-calculated orders improved performance, the only real benefits were in the reverse ordering (E), or the hop approach (F). The most impressive reduction coming from the hop method (F). To further investigate this, further trials were carried out whereby the hop distance was adjusted to find an optimum value.

6. Trial 3 – Varying the hop size

To determine the most suitable hop size a set of three further trials were conducted. As before 1000 randomly selected points were used to conduct 1 million visibility tests in Trials 3A and 3B. For Trial 3C a large sample was taken of 2000 points, resulting in 4 million lines of sight. The locations for these trials were centred on different parts of the city (Figure 3). For these trials the hop size was adjusted after each run in an effort to determine the most suitable value.

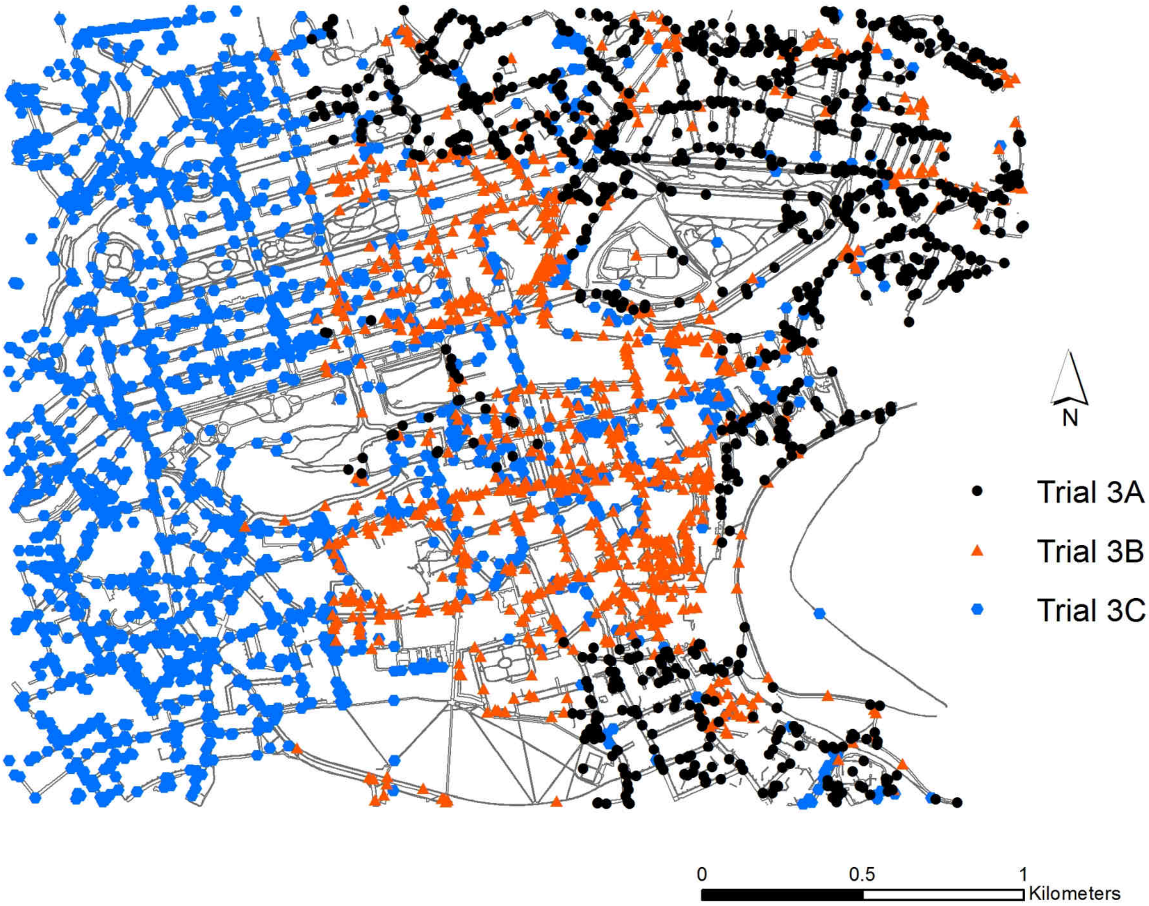

Figure 3: Randomly selected locations in Edinburgh (Scotland) for Trials 3A, 3B*, 3C*

For larger hop sizes there are fewer samples required on each pass but an increase in the number of subsequent 'in filling' passes to ensure that all the sample locations at 1 metre resolution are sampled (Figure 4). The optimum hop size occurs when there is the highest chance of an early sample resulting in a viewing angle above that of the target rendering it out of sight, allowing for LOS termination.

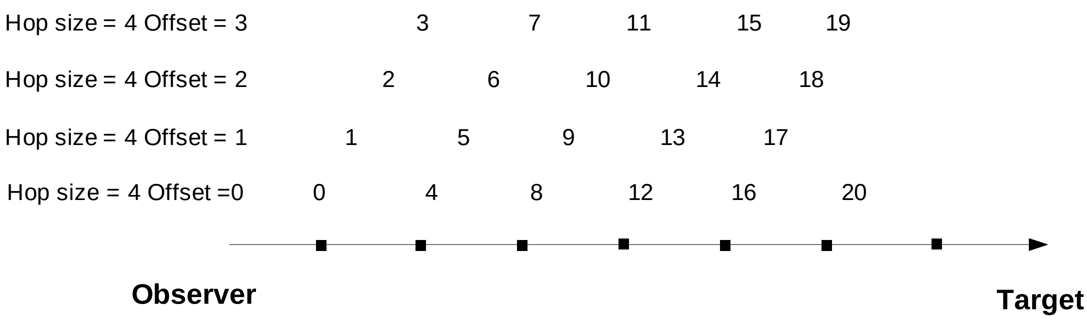

Figure 4: Details of the Hop Size Method

The results from these three trials are shown in Figure 5, and exhibit very similar patterns, whereby the optimum hop size is in the region of 20-40 metres. This would appear to correlate with the scale of roads and buildings within the city region, leading to an early detection of target occlusion. Larger hop sizes lead to a marginal increase in execution time, as more infilling sample locations are required.

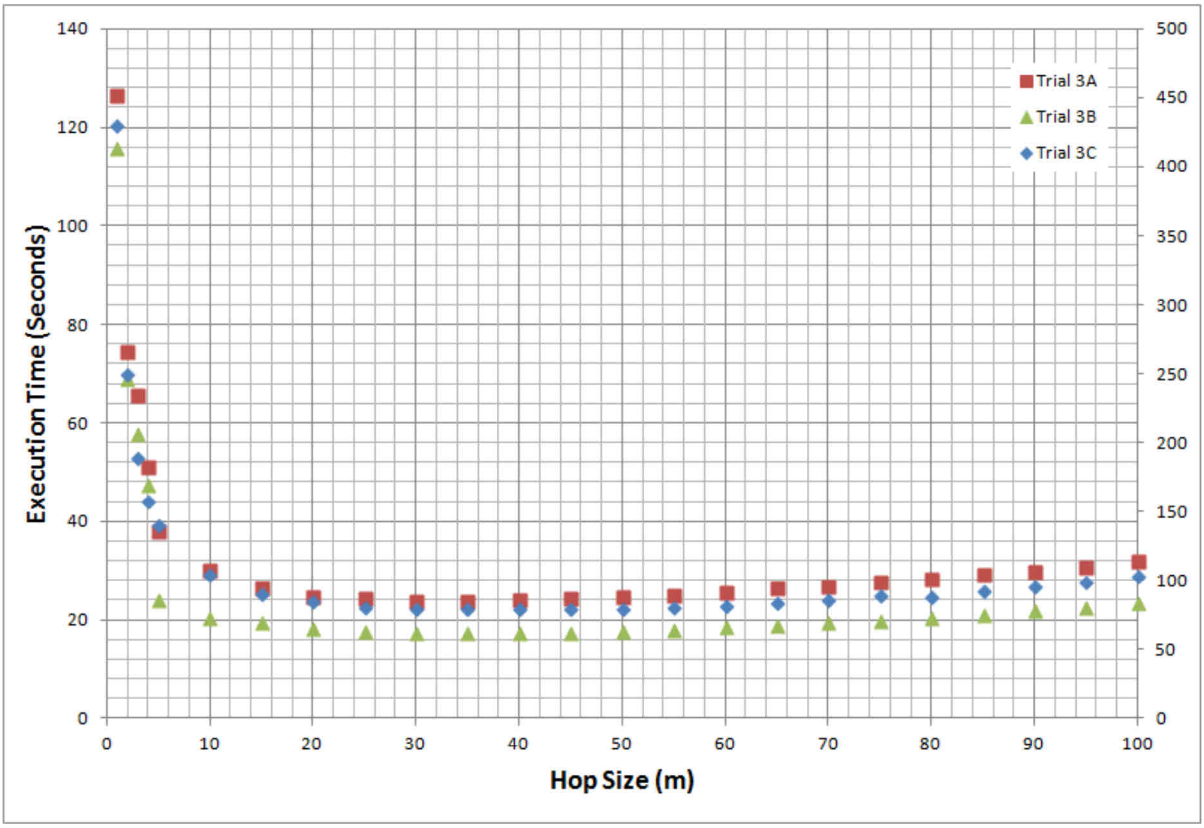

Figure 5: Execution Times with Varying Hop Sizes for Trials (Trial 3C refers to right vertical axis)

A more detailed test for Trial 3A was carried out for hop increments of 1 metre to study in more detail the changes in performance between 20 metre and 40 metre hop sizes. The results show that there is very little difference, but that the slight improvement occurs around 26-29 metres (Figure 6).

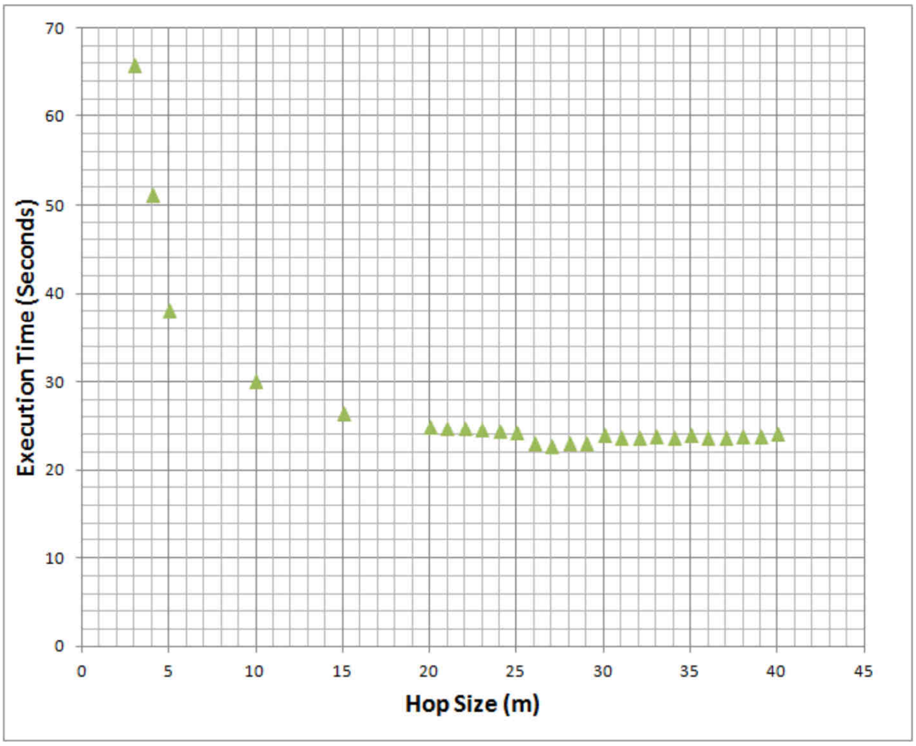

Figure 6: Detailed Examination for Trial 3A

Trial 2 was repeated using a hopsize of 26 metres, with a result found in 18.2 seconds, giving an 8 time performance increase from method A.

7. Conclusion

This research has shown that the sampling order for a line-of-sight plays a significant part in the performance of the algorithm, and that the best performance gains were from introducing a sampling hop. The hop size was varied from 1 metre to 100 metres, and in 3 separate trials the hop sizes from 20 metres to 40 metres was deemed to be the most efficient, resulting in a performance increase in the order of 8 times. Future work should compare the results from other cities, and rural areas to determine the range of hop sizes which are most suited to different topographies. There may also be benefits in introducing different offset values and strategies for hop infilling.

The work has direct benefit in point-to-point visibility analysis, and is particularly pertinent in the context of LBSs where calculations are carried out on devices with more limited processing and power resources.

8. Acknowledgements

The research leading to these results has received funding from the EC’s 7th Framework Programme (FP7/2011-2014) under grant agreement no. 270019 (SpaceBook project).

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8. Biography

Phil Bartie completed his PhD at the University of Canterbury (NZ) before recently moving to The University of Edinburgh to work on the EU funded SpaceBook project. William Mackaness is a lecturer in the School of GeoSciences. Their mutual research interests are in location based services – specifically in the context of dialogue based interaction.