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# HIGH TARGET VISIBILITY ANALYSIS

J. John Kim

U.S. Army Topographic Engineering Center
Simulation, Modeling & Terrain Visualization Laboratory
Alexandria, Virginia 22310-3864
jjkim@tecsun1.tec.army.mil



## ABSTRACT

This paper presents an approach to visibility analysis for a target located high over a terrain made of discrete elevation points. This analysis is a special subset of a general terrain intervisibility analysis problem. It is an efficient algorithm based on a variation of the "line-of-sight" approach, being **k**-times faster than the ordinary approach, where **k** is the ratio of the highest terrain elevation to the target altitude.

## INTRODUCTION

Given a grid made up of discrete terrain elevation points, the visibility analysis for a particular target point located on or above the terrain gr'1 is defined by determining whether or not a specific target point can be seen from all other terrain points. Generally, the complexity of the visibility analysis is proportional to $N^{1.5}$ where N denotes the number of terrain elevation points. This complexity can also be written as a big-O notation, $O(N^{1.5})$. The complexity is derived from the fact that target visibility should be calculated for every terrain point within the grid. This process will take on the average the square root of N steps to calculate. As the number of terrain elevation points N grows larger, (i.e. 1.4 million points within an 1° X 1° DTED cell), it becomes almost impossible to compute dynamically or so called "on the fly." For many cases, however, this "on the fly" computation may be desirable or required. For instance, locating terrain areas which are hidden from a vehicle flying over the terrain is an important task of mission planning. Because these hidden areas would dynamically vary depending upon the current location of the flying object, they should be calculated "on the fly" in order to give the mission planner the opportunity to try all possible variations in search of the best route. It is toward this "on the fly" computation requirement that the scope of this paper is focussed on.

An approach for the special subset of the visibility analysis problem where the target is higher than the highest terrain elevation is given in this paper. An efficient algorithm is proposed and proved as having **k**-times lower complexity than the general algorithm, where **k** is the ratio of the highest terrain elevation to the target altitude. In the following sections, the classical line-of-sight algorithm will be discussed first, followed by a description of the improved, faster version of the algorithm.

## LINE-OF-SIGHT ALGORITHM

The following steps describe the algorithm for the visibility analysis for a target point. All points, except for the target point, are referred to as source points:

1. Visit an unvisited source point.

2. Define a straight line-of-sight line connecting the source point to the target point

3. Walk out along this line of sight from the source towards the target.

4. If any terrain elevation point along the line of sight is higher than the line itself, then label the source as "not visible" (see Figure 1)

5. If the target is reached without intersecting any terrain elevation points, label the source as "visible" (see Figure 2).

6. Repeat for next source point.

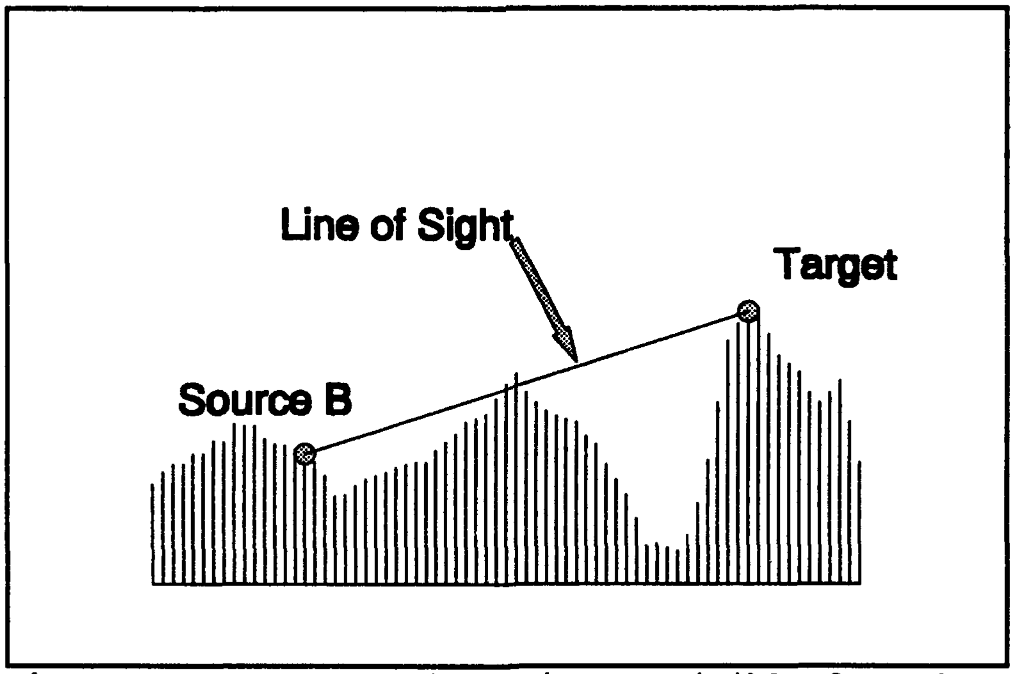


**Figure 1** The source point B is not visible from the target point.

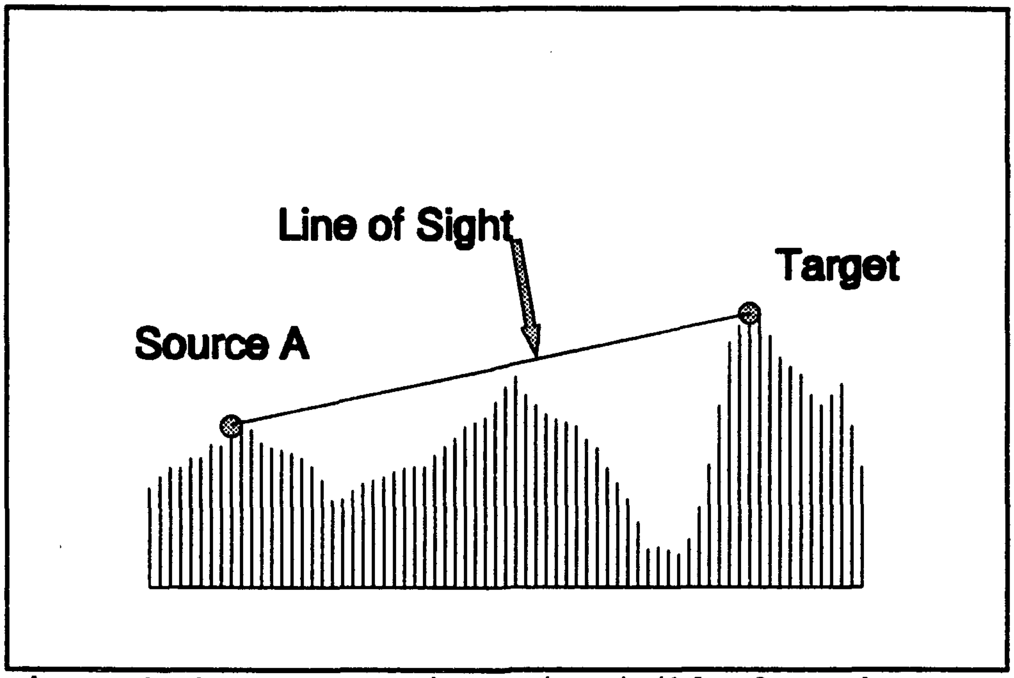


**Figure 2** The source point A is visible from the target point.

The above algorithm can be described mathematically. When a source and a target are decided upon, the line of sight from the source to the target can be expressed as follows:

$$x = f_x(t), \quad 0 \le t \le 1$$
$$y = f_y(t), \quad 0 \le t \le 1$$
$$z = f_z(t), \quad 0 \le t \le 1$$

The terrain elevation data set is denoted by the function.

$$H = G(x, y)$$

Determining the visibility of the source from the target is equivalent to testing whether there exists a t value satisfying the following inequality.

$$G(f_x(t), f_y(t)) \ge f_z(t), \quad 0 \le t \le 1$$

If such a t value exists, the source is not visible from the target. The inequality test can be algorithmically done by ranging the t values from 0 to 1. The increment of the t value may be determined by the grid resolution of terrain elevation points. Since in most cases G is a discrete function, interpolation may be inevitable in order to approximate the left term of the above inequality equation. The inequality test is the most time consuming process in the line-of-sight algorithm. It is this test process that the following proposed algorithm seeks to improve.

## PROPOSED ALGORITHM

The above line-of-sight algorithm is still useful when the target is an object located on the terrain. When the target is located above the terrain, the algorithm can be significantly improved in terms of algorithmic complexity, depending on the target altitude. An improved version of the line-of-sight algorithm is proposed here for the special cases where a target is located at a much higher elevation than the highest terrain elevation point. (The highest terrain elevation is a priori in most cases.) Figure 3 describes the intuitive logic behind the proposed improvement.

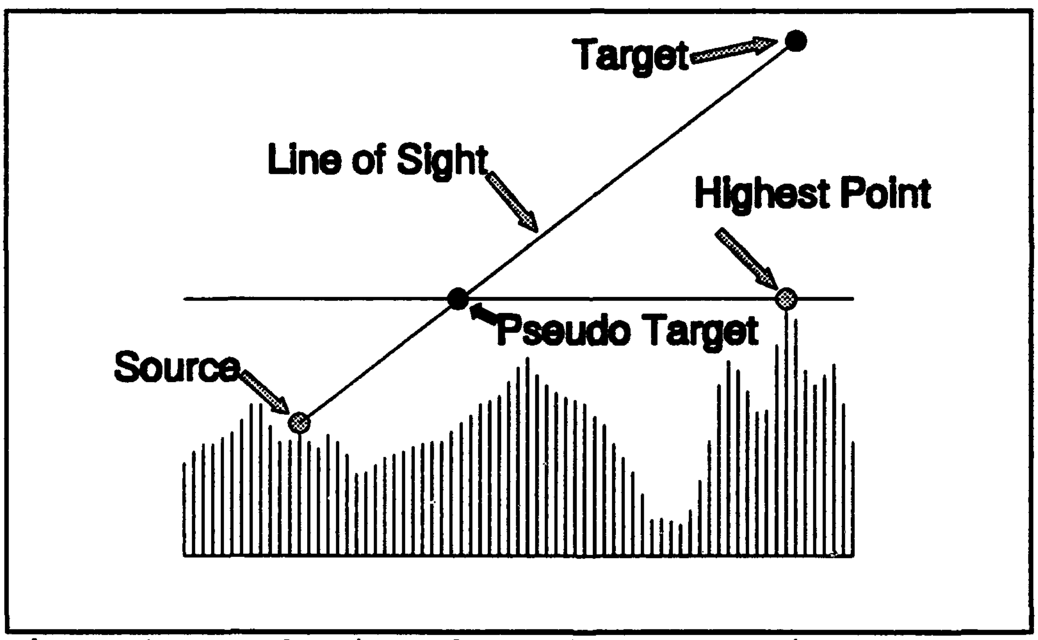


**Figure 3** Introduction of pseudo target point

In Figure 3, the intersection between the line-of-sight line and the horizontal plane containing the highest elevation point is shown as the pseudo target point. The possibility of any terrain elevation point crossing over the line-of-sight occurs only between the source point and the pseudo target point located on the line of sight. The line of sight is always higher than the highest terrain elevation between the pseudo target and the real target. For the previously mentioned mathematical algorithm, the test for the existence of t values satisfying the inequality was done by ranging t values from 0 to 1. However, for special cases where the target is higher than the highest terrain elevation, it is no longer necessary to try all the t values between 0 and 1. The line-of-sight algorithm needs to try only the t values for a certain domain, for example, from

0 to 0.1 for cases where the target altitude is 10 times higher than the highest elevation point. The complexity, or the computing time, of the algorithm is thus improved by as much as 10 times. The walking out along the line-of-sight discussed in step 5 of the basic algorithm is no longer necessary beyond the pseudo target point. The upper limit, $t_p$, of the t domain for which the t values are tried against the inequality test, and the corresponding pseudo target point $(x_p, y_p, z_p)$ are derived from the previous line-of-sight equations and the highest terrain elevation, h, as follows:

$$
\begin{aligned}
t_p &= f_z^{-1}(h) \\
x_p &= f_x(t_p) \\
y_p &= f_y(t_p) \\
z_p &= f_z(t_p) = h
\end{aligned}
$$

Accordingly, Step 5 in the previous algorithm should now read as follows:

> 5. If the pseudo target point is reached without intersecting any terrain elevation points, label the source as "visible."

The previous inequality equation stays the same except that the upper limit of the t domain now changes from 1 to the far lesser value of $t_p$ :

$$G(f_x(t),\ f_y(t)) \geq f_z(t),\ 0 \leq t \leq t_p$$

The validity of this change is obvious, because the terrain can not cross the line-of-sight between the pseudo target and the actual target as is illustrated in Figure 3. Instead of a formal proof , it will be shown that the complexity of the test process is upper-bounded by a constant of a value much less than 1. The pseudo target is always on the horizontal plane $z = h$ and varies only in the x and y coordinates, depending on the varying source coordinates $(x_{source}, y_{source}, z_{source})$. Let $(x_{target}, y_{target}, z_{target})$ be the fixed target coordinates. Then, the line of sight will be:

$$
\begin{aligned}
f_x(t) &= x_{source} + t(x_{target} - x_{source}) \\
f_y(t) &= y_{source} + t(y_{target} - y_{source}) \\
f_z(t) &= z_{source} + t(z_{target} - z_{source})
\end{aligned}
$$

The t value corresponding to the pseudo target, $t_p$, is:

$$t_p = f_z^{-1}(h) = \frac{h - z_{source}}{z_{target} - z_{source}}$$

Since the following inequalities among the highest terrain elevation, the target altitude, and the source height always hold

$$z_{source} \leq h < z_{target}$$

the $t_p$ is upper-bounded as follows:

$$t_p = \frac{h - z_{source}}{z_{target} - z_{source}} \leq \frac{h}{z_{target}}$$

The highest elevation **h** and the target altitude $z_{target}$ are known constant values. Therefore, $t_p$ is upper-bounded by a constant:

$$G(f_x(t),\ f_y(t)) \geq f_z(t), \quad 0 \leq t \leq t_p \leq \frac{h}{z_{target}}$$

This makes the complexity of the test upper-bounded, and the proposed algorithm becomes **k**-times less complex than the classical algorithm with t domains always between 0 and 1 (where **k** is the reciprocal of the upper-bound, which is the ratio of the highest terrain elevation to the target altitude).

## CONCLUSIONS

This paper has shown that the classical line-of-sight algorithm can be significantly improved for special cases where a target is higher than the highest terrain elevation. The algorithmic complexity of the improved version has been analyzed and shown as having an upper-bound which is quantified by the ratio of the highest terrain elevation to the target altitude.