Efficient Line-of-Sight Computation by 3D Environment Reconstruction

Introduction

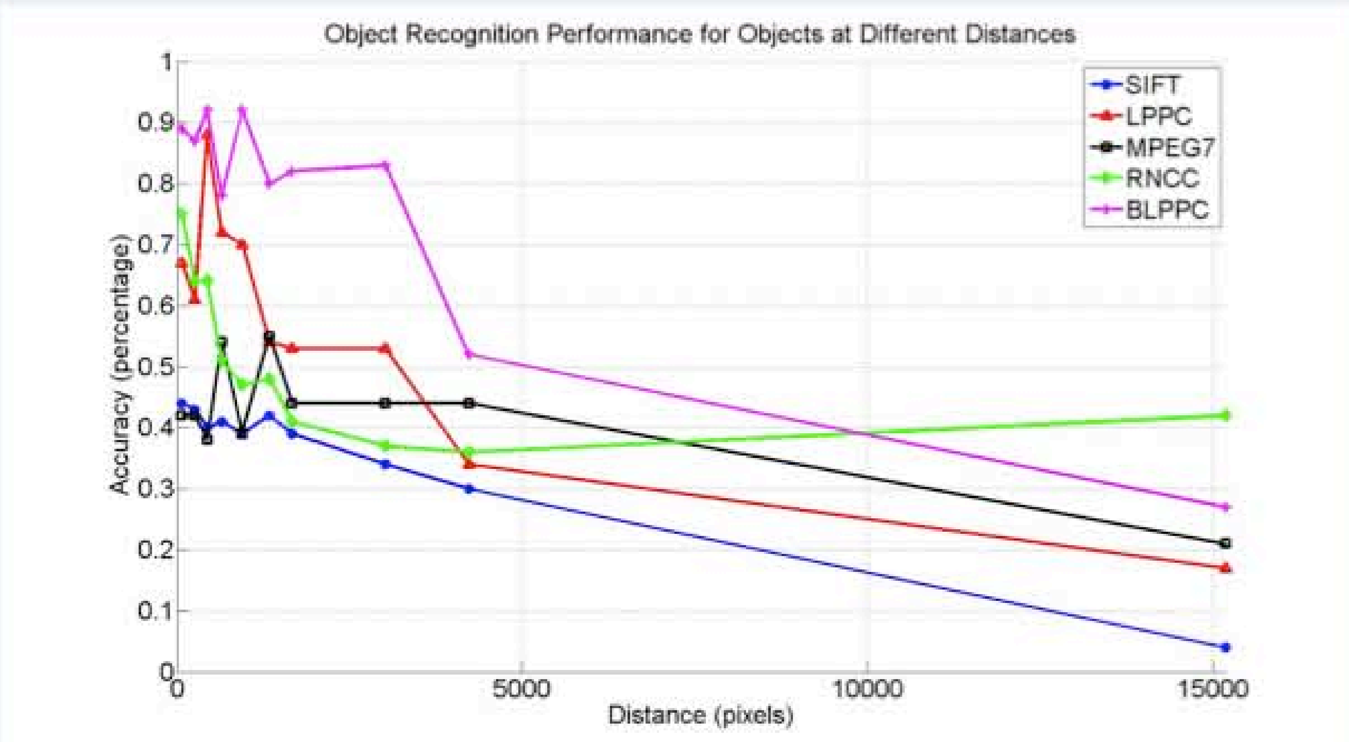
It is imperative that safety critical assets can be observed by train drivers from prescribed distances. These distances are currently measured using a manual system. However, this presents several disadvantages, including: a massive amount of manual labour is required and rail track sections must be closed during the measuring process. Automation of this process can thus provide several advantages. This automation would typically take the form of fixing video cameras to trains, running trains down sections of track containing important assets, capturing video information of the asset and the surrounding environment. The video can then be processed offline to determine the line-of-sight to the asset.

Figure: Example Assets

Once the video has been collected from the train mounted cameras, it must be analyzed in some way to determine the line-of-sight to an asset. For which, 2D object recognition methods seem an obvious choice – applied to the 2D video frames. A typical structure for such a method to determine line-of-sight would be:

- Train 2D object recognition methods with the assets to be identified
- Locate an image containing an asset of interest
- Step backwards through the image sequence, performing object recognition until the asset is deemed no longer visible

The below graph shows the results for different object recognition methods, recognizing assets at different distances. This clearly shows that performance of these types of methods decreases with increasing distance to the asset recognized, as the asset becomes smaller in the video frame processed.



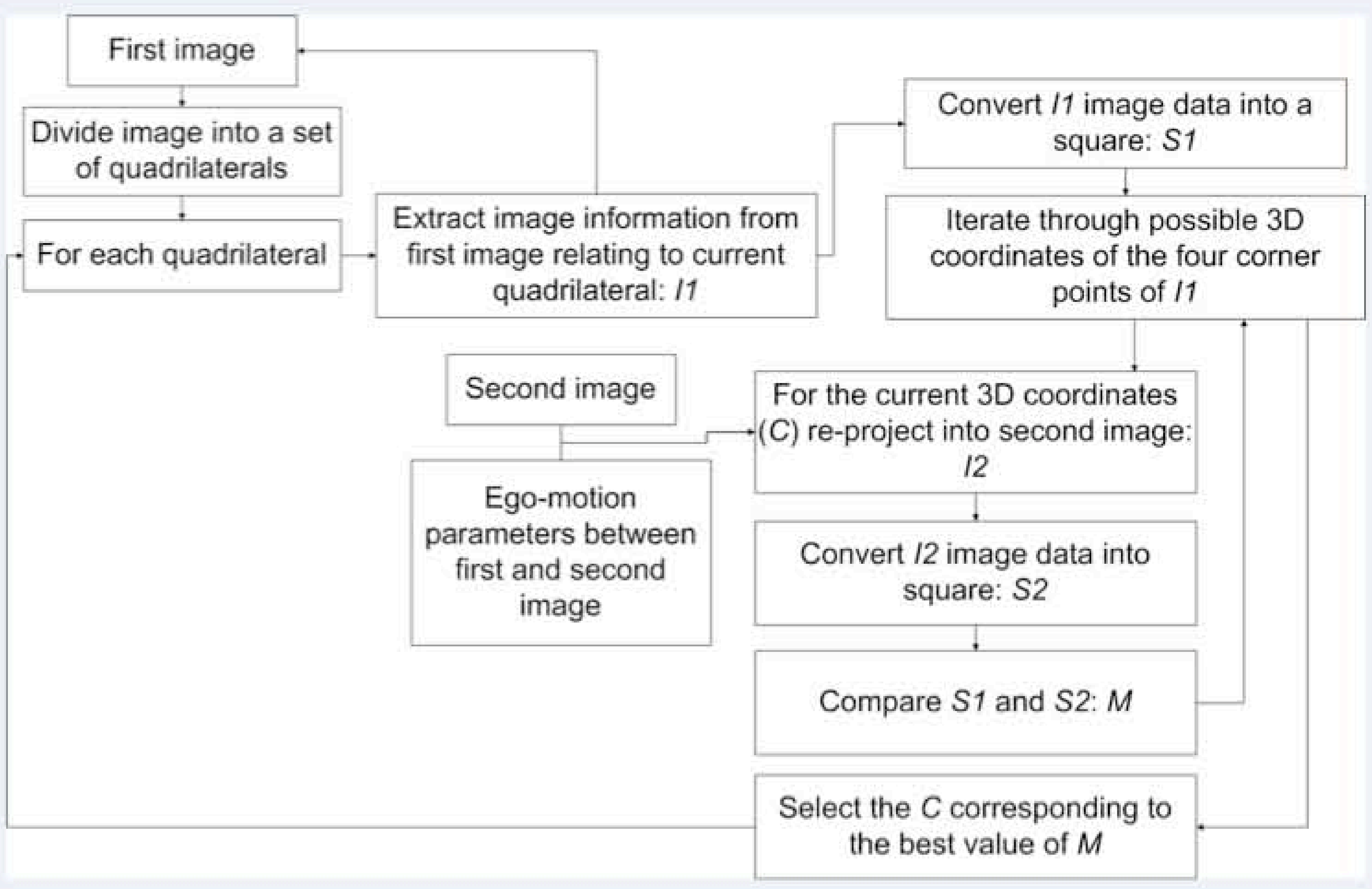
The motivation behind this research is, therefore, to develop a method which is capable of performing automatic line-of-sight analysis from monocular video, which minimizes any limitations introduced by the hardware. As a result, there are two distinct parts to the resulting approach:

1. Create a 3D reconstruction of the scene
2. From 3D reconstruction data, create model used for line-of-sight analysis

Reconstructing 3D Scenes

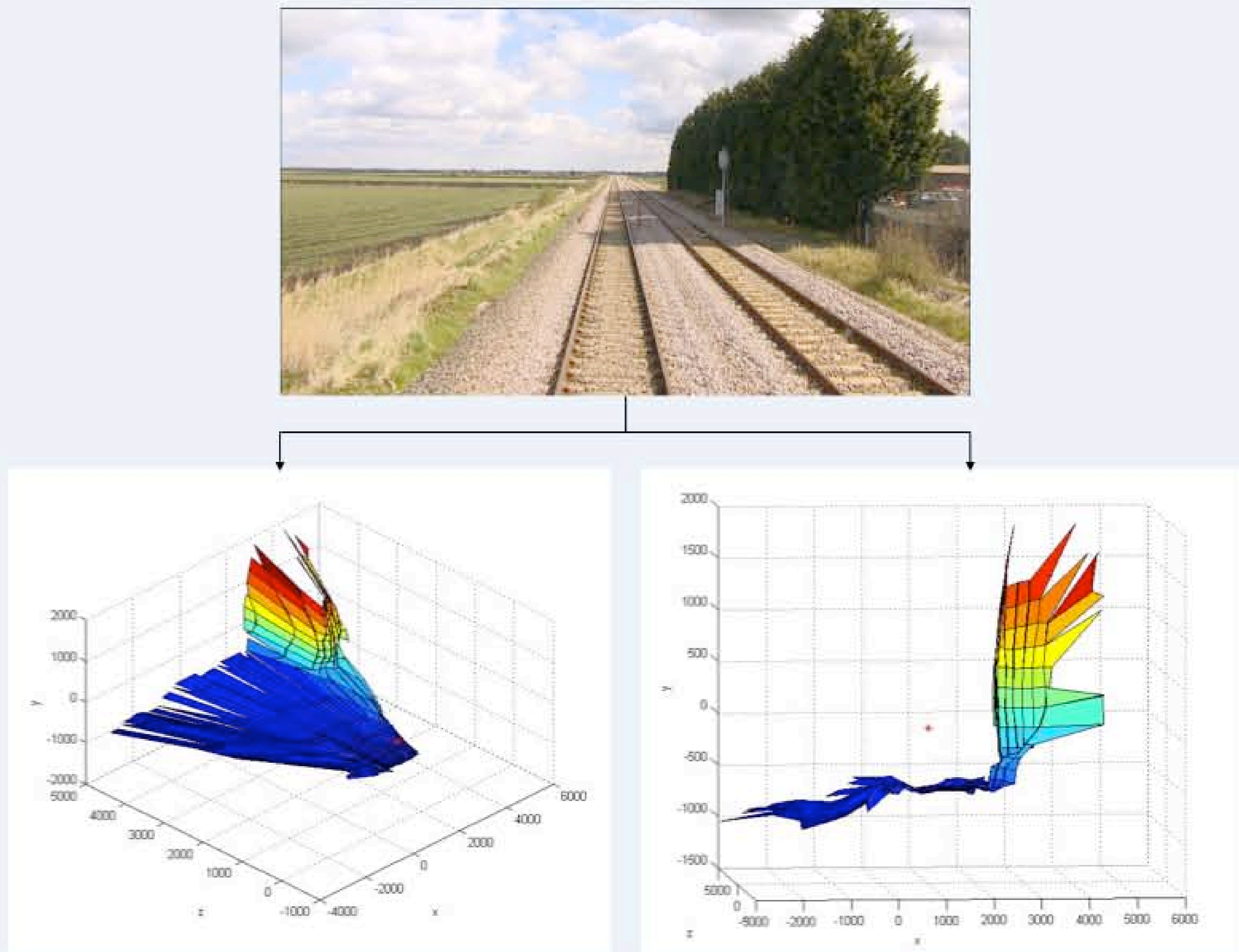
Typical methods for reconstructing a 3D scene rely on specialist hardware such as: lasers, structured lighting systems or stereo cameras. Monocular methods (required in this application) compute shape from motion by matching features across frames. These methods search the 2D image space for correspondences and combine with estimated camera motion to recover 3D information.

I propose a different technique which performs plane matching by searching the 3D scene space:



Therefore, a space of possible 3D coordinates is searched for the best fitting plane to a quadrilateral in the 2D image space. However, this space can be quite large, but can be restricted using a set of geometric constraints to ensure only plausible planes are checked.

Example 3D Reconstruction



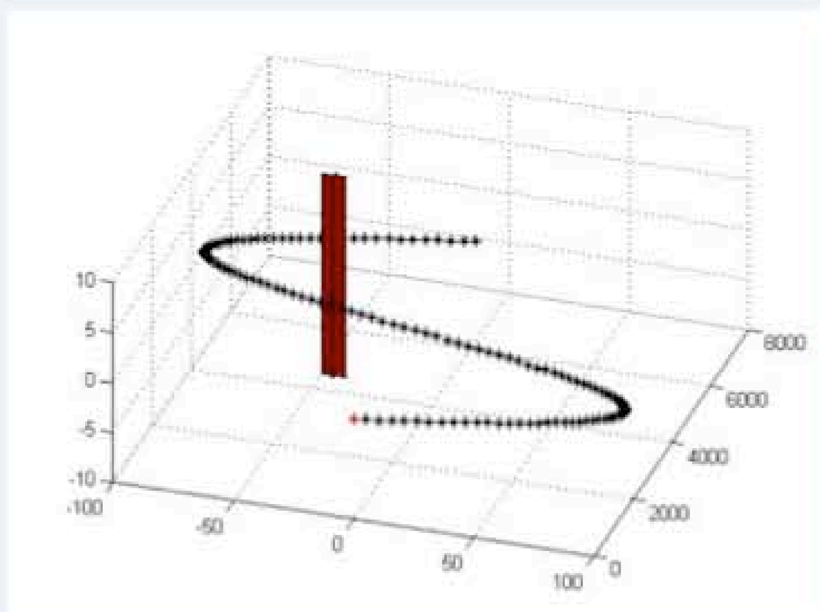
Line-of-Sight Analysis

Three-dimensional data has been reconstructed, now it needs to be analyzed in some meaningful way. But what do, we want to know?

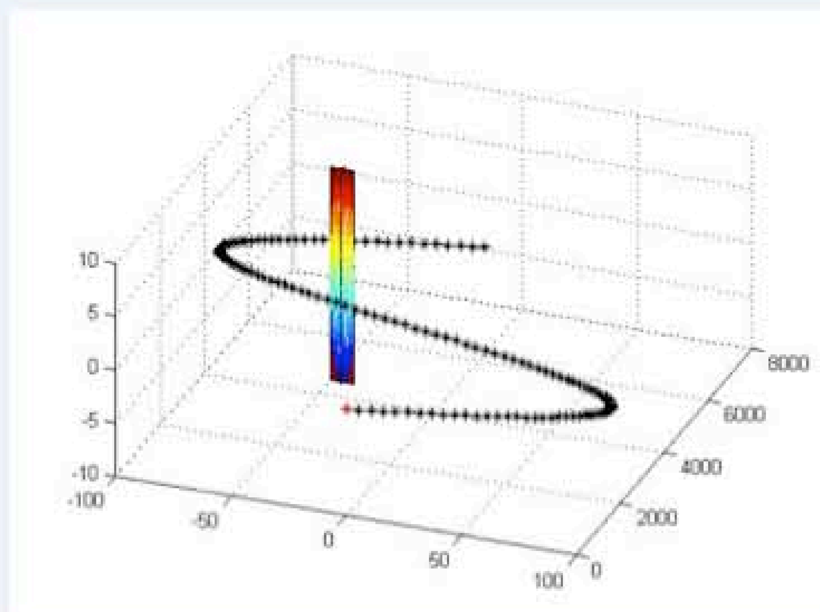
For an asset:

- Which items of terrain are blocking the line-of-sight to the asset
- What happens if these terrain features move? (i.e. trees grow)

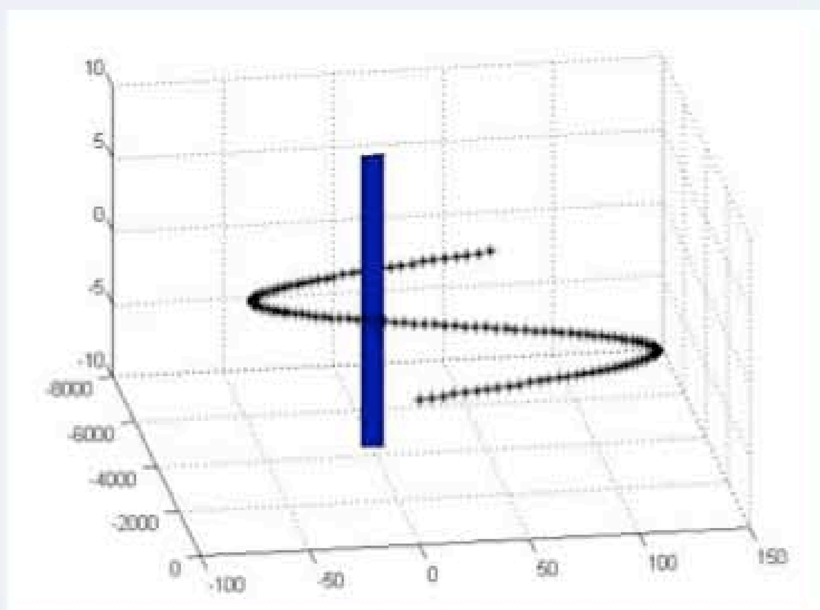
Can use the following method of modelling terrain elements and analyzing line-of-sight:



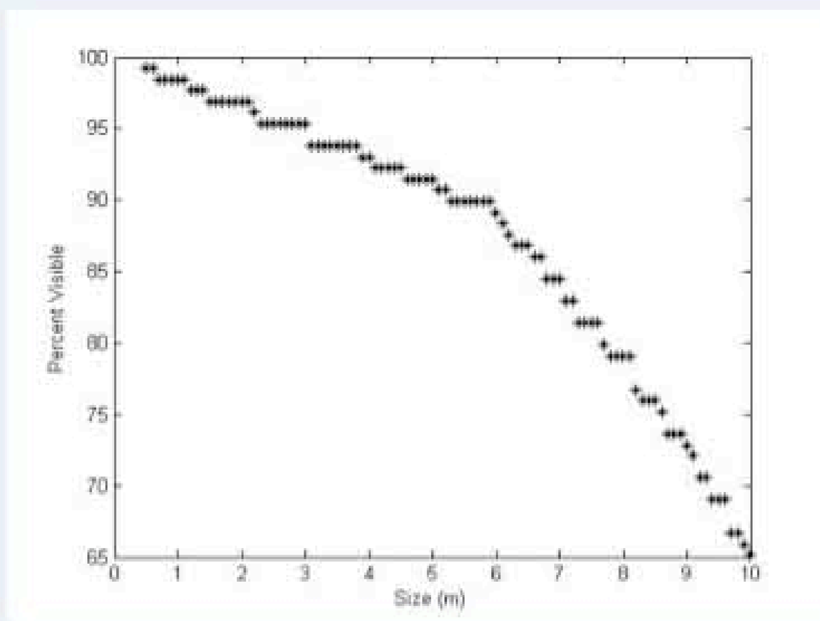
Create a model containing a set of observation points (black) from which we want to know the visibility to the asset (red), given that the terrain elements (planes) may block this line-of-sight.



Model the terrain elements with ellipsoids.



1) Compute 'bounding plane' around ellipsoid
2) Rotate scene so the asset point is 'looking towards' the bounding plane
3) Any observation points 'behind' the plane and appearing within it from the current viewpoint are obscured



Using the equation of an ellipsoid, it is now possible to model how the line-of-sight changes with the changing size of the ellipsoid.

$$\frac{(x-xc)^2}{m \times xr^2} + \frac{(y-yc)^2}{m \times yr^2} + \frac{(z-zc)^2}{m \times zr^2} = 1$$

Varying m, the size of the initial ellipsoid will be altered. So, it is now possible to analyze the terrain modelled by the ellipse by plotting m against the percentage of observation points visible (above).

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