Quantifying and visualising the uncertainty in 3D building model walls using terrestrial lidar data.

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Abstract
At Ordnance Survey, we are investigating methods of assessing the quality of 3D building data that are relevant to users. Many 3D building models are derived by capturing the roof shape from aerial data and inferring the wall shape either by dropping the roof edges to the terrain or extruding a building footprint up to the roof. This method can provide accurate representations of roofs and good placement of the building as a whole. However, since many uses of 3D data are from the viewpoint of a ground level observer, these methods for modelling building walls may be inadequate. To compare methods for modelling walls, a technique is required to derive the difference between the model and reality.

We propose a method that uses terrestrial lidar points as a reference dataset. The points are captured from a static location and filtered using both manual and automatic techniques. A closed volume between the point cloud and the wall model is then derived by projecting the lidar points onto the building model along the line of sight of the laser. The resulting polyhedra help to identify specific differences between a building model and the real world, giving both quantitative and qualitative measures.

Keywords: 3D city model, quality assessment, uncertainty, lidar, photogrammetry

1. Introduction
Ordnance Survey Research is currently investigating the collection, analysis and storage of 3D building models. Part of this work is to develop methods of assessing the quality of such models, since it is important that any future Ordnance Survey product meets the expectations and requirements of our customers (Sargent et al. 2007). As many potential uses of 3D models are from the viewpoint of a ground level observer (Sargent et al. 2007), the quality of modelled walls with respect to these uses is being investigated.

Buildings in 3D city models are usually constructed from four components: the roof shape, the footprint, a digital terrain model (DTM) and walls. Footprints and DTMs are already available from national mapping agencies or other providers of mapping data. The collection of roof shapes, or at least heights, can be achieved using existing techniques, such as photogrammetry or airborne lidar. However, walls are relatively neglected and are usually generated as vertical planes either by extrusion of the footprint up to the roof height (e.g. Stilla et al. 1999, Schulze-Horsel 2007) or by dropping the roof line down to the DTM (e.g. Baillard et al. 1999, Takase et al. 2003). When modelling anything but the simplest of buildings, these processes may not produce realistic representations of walls because they neglect projecting features such as ground floor extensions, balconies and other juts and recesses that change the horizontal cross-section of the building between ground and roof levels.

Previously, 3D building models have been quality assessed (e.g. Guarnieri et al. 2004, Kaartinen et al. 2005) but the impact of model quality on specific user tasks has not been investigated. If 3D building models are to be used for analytical purposes, such as line of sight analysis, it is essential to be able to assess the quality of wall representations. This would allow both the improvement of techniques for generating the buildings and also provide an objective measure of confidence in such models.
In this paper we briefly describe the development of a method for assessing the quality of walls in 3D building models against a reference data set.

2. Data

For the development of the quality assessment methodology, 3D building models were created using building footprint polygons from the OS MasterMap® Topography Layer. Heights were applied to the polygon vertices using a DTM. The simple 2.5D building models were then generated by providing a fixed height for the building (e.g. Amiri Parian et al. 2007) (see Figure 1).

A reference data set was required that provided detail of the walls from the point of view of a ground-level observer. We chose terrestrial lidar data, captured from a stationary (vehicle or tripod) platform that provided a high density of points (see Figure 2).

The data used for the development of the methodology were from a van-mounted scanner that was generally positioned within 50m of the target building. The angular separation between points is fixed during the scanning process, which leads to uneven spacing of the points on the target. Nominally, point separation was 10cm.

3. Methodology

The reference and model data were processed in five stages, described below, to produce polyhedra that could be visualised and measured to understand how the 3D building model walls differ from the reference data. The MATLAB® environment was used for all data processing.

3.1 Removal of non-wall reference points

The reference (lidar) point cloud was filtered to remove points relating to features between the scanner and the target building, such as the ground and vegetation, as well as returns from internal walls collected through windows and other openings. Work on automating the filtering process is ongoing, but the general approach was to initially select only those points within a maximum horizontal distance of the building footprint and then select only those points that form the largest planes within the remaining point cloud.

3.2 Projection of reference points onto model

The points were projected onto the 3D model along the line of sight from the lidar scanner location. This identified where the reference point would have fallen had the building model matched the reference data. The reference points were associated with the building model on a face by face basis so that the quality of each face could be determined separately.

3.3 Triangulation of reference points

The connectivity between the points in the lidar point cloud was established by triangulating the points. This was achieved by projecting the reference points along the line of sight of the scanner onto the surface of a sphere centred on the scanner location. The convex hull of the projected points was then found using QHull (Barber et al. 1996). The resulting triangulation of the points on the sphere’s surface was then applied to the reference points in their original locations forming a reference surface from the reference...
points. The same triangulation was also applied to the corresponding points that had been found on the modelled walls in the previous stage.

3.4 Separate reference surface into regions

The reference surface was separated into regions so that no region intersected the 3D model. This was achieved by removing the triangulation edges that connected reference points on either side of the model face. Dividing the reference surface into such regions ensured that the polyhedra created in the final stage from the reference and the model data sets did not self-intersect.

3.5 Forming error polyhedra

Polyhedra were formed by finding the edge points for each reference surface region and connecting these to their corresponding projected points on the model. This was achieved by joining the equivalent triangles from the edge of each surface region to form a triangular prism (see Figure 3), then discarding all faces except those made up of edge vertices. The method used for this stage also ensured that all triangles joining the reference and projected surfaces were ordered either clockwise or anti-clockwise i.e. their normals point either into or out of the polyhedron. It was also necessary to switch the vertex order of either the reference surface or the projected surface (depending on whether the error was in front of or behind the model face), to ensure consistency across the whole polyhedron.

4. Results

The resulting error polyhedra can be displayed to visualise the difference between the model and reference data. A measure of this difference is the volume of the polyhedra. This can be calculated using the method of Zhang et al. (2001) since the final two stages have ensured that the surface is not self-intersecting and that the vertex order of all surface triangles is either clockwise or anti-clockwise. By excluding polyhedra with a small volume, we can visualise significant regions of difference between the modelled vertical walls and the reference point cloud. For example, in the case illustrated in Figure 4, it is clear that using the footprint as the template for the building walls is only valid for the ground floor of the building.

5. Discussion / Analysis

Using this method, we have calculated just one quantitative measure of error – the volume of the polyhedron. Other measures, such as measures of shape, may also prove valuable. For example, large thin volumes with large surface to volume ratios may denote relative errors between the reference point cloud and the building model.

Representing error as polyhedra is appropriate to tasks that work with volumes such as line of sight analyses. However, more work is required to understand just how such differences in the morphology of 3D models and the actual building can affect the accuracy of such uses of 3D data.

The quality of the resulting polyhedra is dependant on the positioning of the scanner. A single scan taken from a stationary location will not capture all detail and obscured features could result in significant errors. When projecting reference points onto the model, many points in the reference dataset will not intersect the model. This method can only assess the quality of the model in the areas for which we have reference data. This method therefore relies on point clouds scanned from carefully selected locations. We also intend to extend this method to work with multiple scans and moving platforms.

This method has been developed with the aim of assessing the quality of building walls, but it can be extended to use with other features such as building roofs.
6. Conclusions

The aim of this work was to develop a method to assess the quality of walls in 3D building models. The method described here will identify large morphological errors in the structure of the building model compared to a reference point cloud collected from a fixed position at ground level. The description of errors as polyhedra also allows consideration of the shape and location of errors, rather than statistical measures. Therefore quantities such as volume and surface-to-volume ratio can be considered, which may be more meaningful in a surveying context. Such representations of error also provide clear visual indications of morphological discrepancies.

The next stage in this work will be to analyse a sample of building model walls, generated in various ways, in order to assess their validity and investigate accurate methods of model construction. The error analysis method will also be extended, firstly, to combine polyhedra generated from multiple stationary view points, which would provide better representations of the errors, and then, so that lidar data collected form a moving platform, such as a van or aircraft, can be used.

7. References


