Automatic 3D Urban Building Extraction & Reconstruction from Multi-ray Photogrammetry

McClune A. [1], Miller P. E. [1], Mills J. P. [1], Holland D.[2]

[1]School of Civil Engineering and Geosciences, Newcastle University, United Kingdom [2]Ordnance Survey, United Kingdom

Introduction

The demand for 3D building models has grown significantly over the last 20 years (Haala and Kada, 2010). Successful reconstruction of roofs is highly dependent on the resolution and accuracy of the underlying data that is extracted and used. A significant body of research has investigated the integration of lidar and aerial imagery for building reconstruction. However, differences in time of capture can cause registration errors and hinder reconstruction. Recent developments in digital aerial image acquisition and processing have led to high resolution imagery and the production of dense point clouds.

This research aims to build on these advances to investigate the extraction of high resolution data from multiple outputs of a single aerial image capture and explore how these can be used to improve automation in 3D building reconstruction.

Multi-Ray Photogrammetry

Since the introduction of large format digital aerial cameras at the turn of the 21st century, there have been major advances in aerial image acquisition and processing. These advantages include;

- Images captured at 80% forward overlap and 60% lateral overlap increasing the number of stereo combinations;
- Images captured in near infrared as well as RGB;
- Smaller ground sampling distance resulting in higher resolution imagery of 0.1m or less;
- Algorithm development which can match pixel to pixel to produce a point cloud with densities over 100 points per m² and high redundancy;
- True orthophoto production from high resolution DSMs.

Methodology

Edge Detection

Edge detectors are being investigated to extract roof edges as well as ridge and valley lines. The results are promising with approximately 78% of edges being extracted but these are influenced by shadow and texture as shown in Figure 1 using the Canny edge detector.

Roof Type	Edge Detection (%)
Flat I	82.15
Flat II	73.43
Gable	79.28
M-Shaped	86.71
Hipped	87.87
Cross Gabled	81.54
Complex	82.54

Table 1. Edge detection results for various roof types using the Canny edge detection operator

Figure 1. Edge detection results (red) from a. Flat roofed building and b. M-Shaped roofed building overlaid onto the orthophoto

Scan Line Segmentation

A clear description of the roof shape can be seen by taking a cross section, referred to as a scan line, from the DSM, as shown in Figure 2;

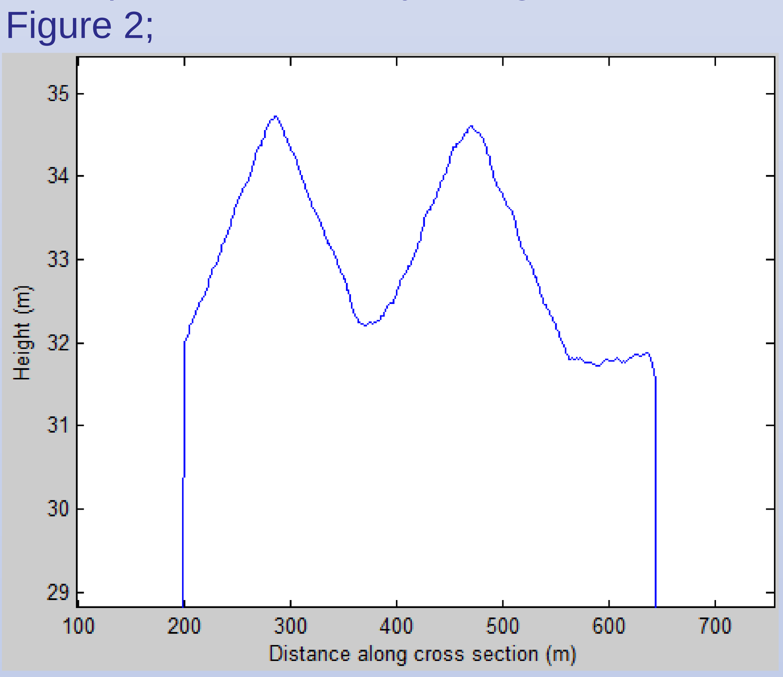

Figure 2. Cross section of an M-Shaped roof with a flat section.

The segmentation of images into planes using scan lines was first proposed by Jiang and Bunke (1994). Planar breakpoints were iteratively determined from a scan line when the distance from a point to a line segment was greater than a pre-defined threshold. This was applied to a 0.5m lidar DSM for roof reconstruction but found to be inaccurate for break point detection (Haala and Brenner, 1999). However, as DSMs from multi-ray photogrammetry are produced at a spatial resolution equivalent to the imagery there is now potential to extract information at a much higher level of detail.

Breakpoints are detected across a profile by a change in sign of the numerical gradient. A threshold of ±0.5m was used to classify flat, positive and negative sloped planes by measuring the height difference between breakpoints. The major roof planes and smaller planes from dormer windows, which are usually not classified, are successfully detected as seen in Figure 3a and Figure 3b. Whilst there is a correct separation of planes the accurate position of breakpoint is not always detected.

The angular slope between breakpoints was also measured with the results shown in Figure 3c and 3d. This improved the delineation of neighbouring planes as well as correctly classifying corners of planes.

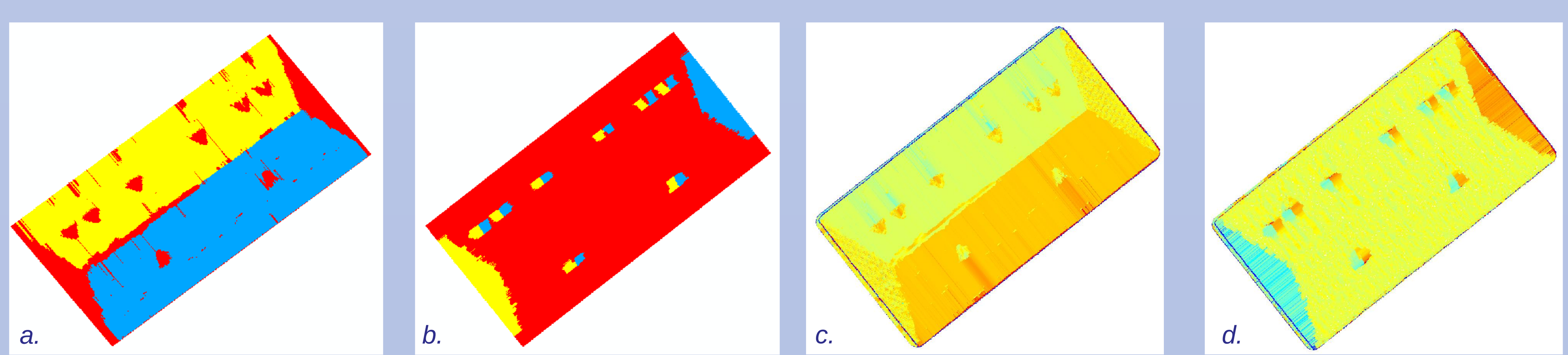

Figure 3. X and Y scan line segmentation using height threshold (a,b) and grouping by angular slope (c,d)

Curvature and Roughness

Vegetation which either overhangs a roof or is in close proximity to the building can hinder reconstruction. The curvature and roughness of a point was measured within an neighbourhood in order to segment trees from rooftops.

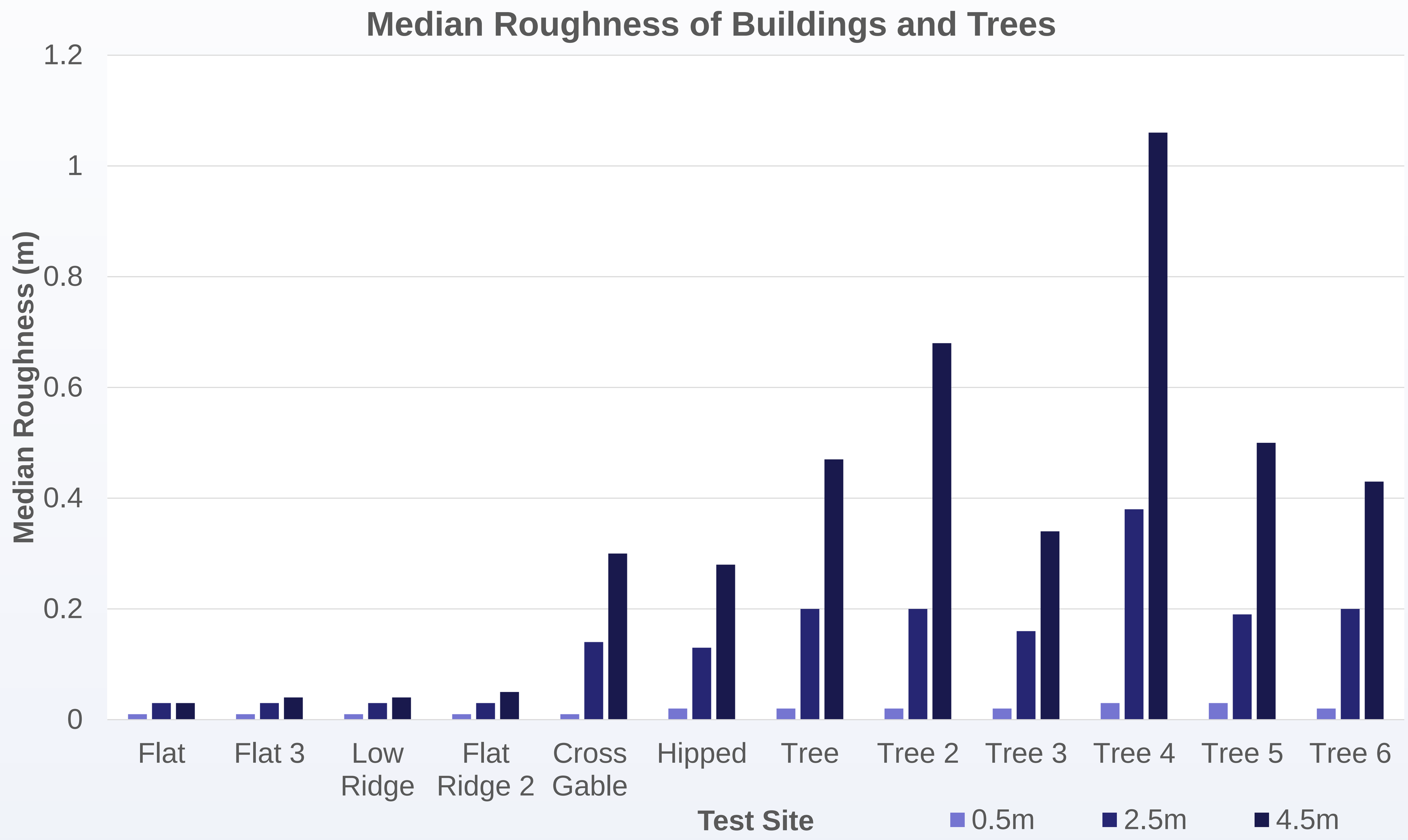

Figure 4. Median Roughness values for different roof and tree types

Using a 2.5m neighbourhood size and a 0.16m threshold, trees were segmented from roof planes. However, ridge lines were also included in the classification as shown in Figure 4.

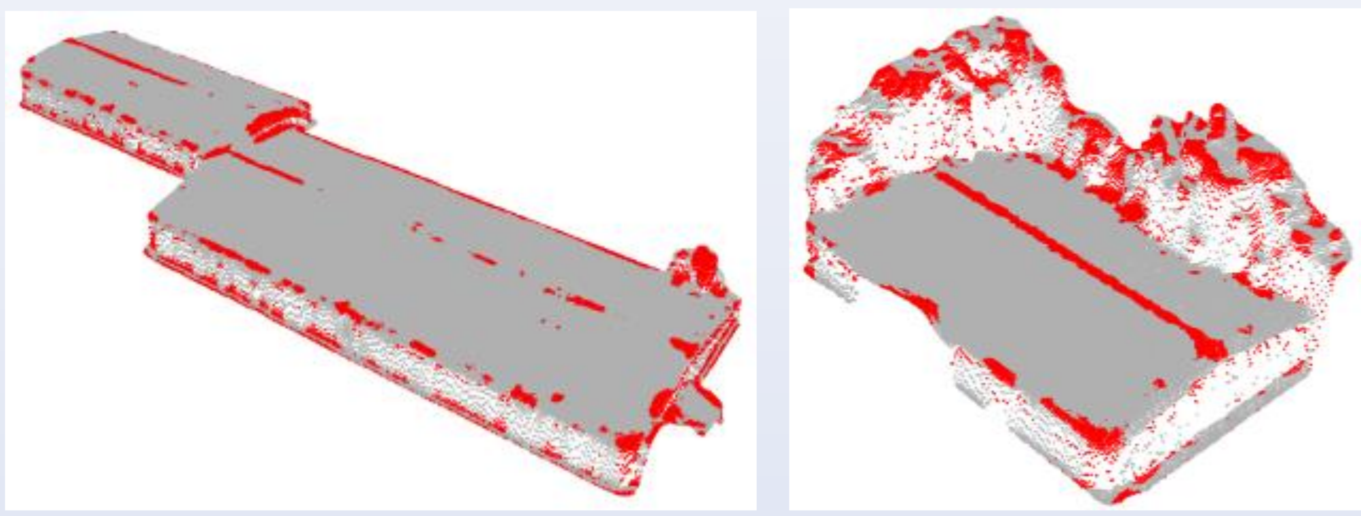

Figure 4. Building with neighbouring trees showing areas above the threshold (red) and below the threshold (grey)

Integration of data

None of these results can be used independently for 3D reconstruction of building models. However, the integration of these datasets can help overcome their individual limitations and remove erroneous data.

To improve the scan line segmentation, edges detected by the Canny edge detector were used as breakpoints along a scan line. Using the Canny edge detector has been shown to extract positionally accurate roof break lines. The angular slope was then measured between detected breakpoints, with the results presented in Figure 5. The planes have again been successfully detected and the delineation of neighbouring planes has improved with straight edges being extracted. The definition of the dormer windows is also improved using the edge detection as breakpoints, compared to detecting breakpoints as changes in sign of numerical gradient.

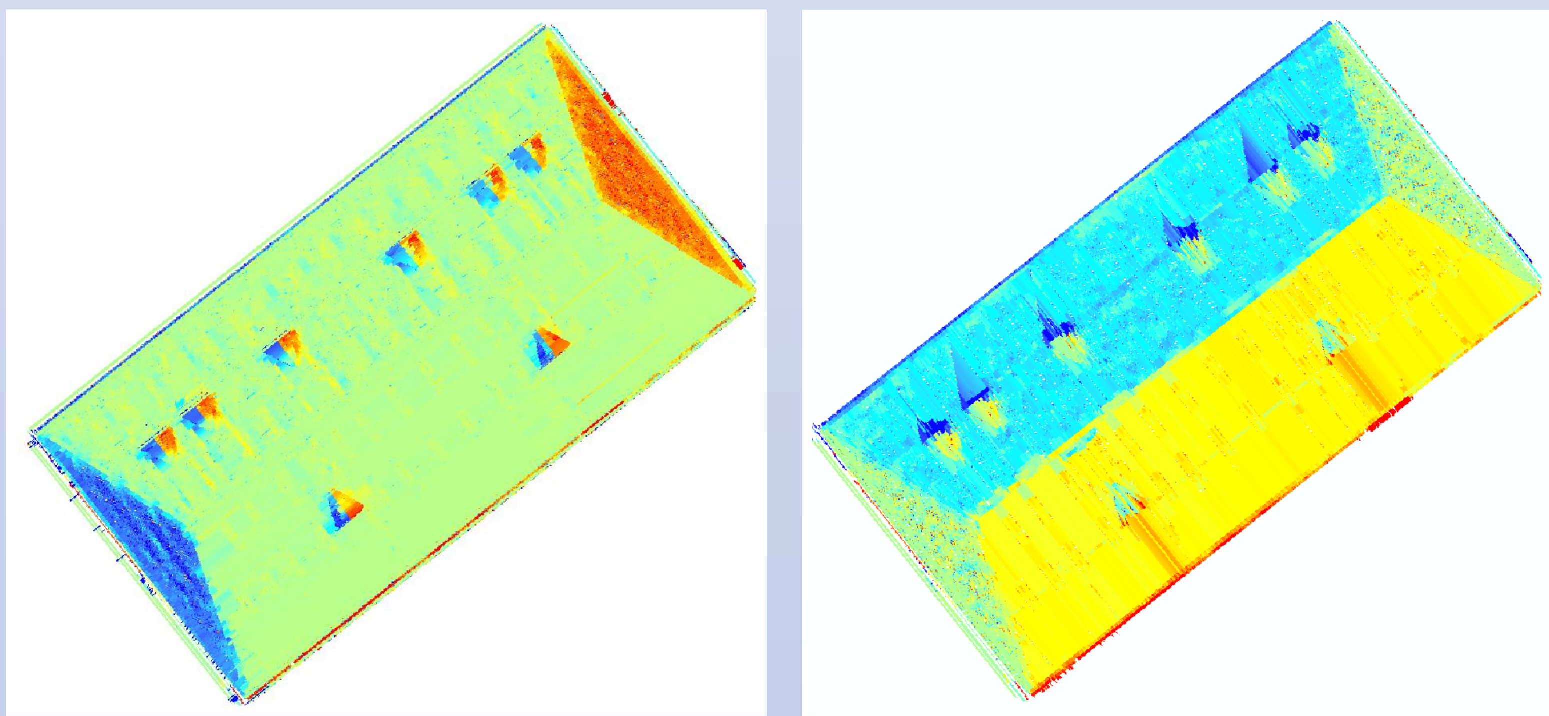

Figure 5. 2D Scan line segmentation using breakpoints from Canny edge detector

Conclusion & Future Work

This study has shown how scan line segmentation can be used for the segmentation of roof planes from a DSM as well as extracting small roof features such as dormer windows. The planes are successfully segmented but the exact position of the break points between planes is not extracted using changes in height or angular slope. It has also shown the complementary nature of 2D and 3D features and how they need to be used in synergy to reconstruct a 3D building model. Research has been undertaken to explore the segmentation of nearby trees and whilst parts of the tree are classified using roughness, more information is needed to improve the classification.

Further work is to be undertaken. Whilst using the detected edges as breakpoints improves the position of break lines for planes, if an edge is not detected the scan line segmentation fails. Therefore other datasets are to be included to overcome missed edges. The clustering of line segments is to be investigated in order to extract roof planes. These roof planes will then be used to create an accurate roof model and the creation of a Level of Detail 2 building model, as outlined by OGC's CityGML standard. Image segmentation techniques such as image texture will be explored to aid the segmentation of trees and buildings.

References

Haala N, and Kada, M. (2010) 'An update on automatic 3D building reconstruction', *ISPRS Journal of Photogrammetry and Remote Sensing*, 65(6), pp.570-580

Haala, N. and Brenner, C. (1997) 'Generation of 3D city models from airborne laser scanning data', *Proceedings 3rd EARSEL Workshop on LIDAR Remote Sensing on Land and Sea. Tallinn, Estonia 17-19 July, pp.* 105-112.

Jiang, X. and Bunke, H. (1994) 'Fast segmentation of range images into planar regions by scan line grouping', *Machine Vision and Application*, (7), pp. 115-122.

Acknowledgements

This project is part funded by the Ordnance Survey and ESPRC. The authors would like to thank Ordnance Survey for the provision of aerial imagery, photogrammetric point cloud and DSM.